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This study is an evaluation of Apra Harbor, Guam as a typhoon "haven." Characteristics of the harbor discussed include facilities available, wind and wave action, storm surge and the topographical effects on winds prior to and during passage of tropical cyclones. Problems to be considered if remaining in port and possible evasion procedures

20. Abstract (continued)

for ships sailing from the port are examined.

The tracks of tropical cyclones from 1947-1973 for the western North Pacific were analyzed to determine the probability of threat to Apra Harbor. Observations by the authors and information obtained in conversations with port and harbor authorities are utilized in reaching conclusions.

In general, the results indicate that Apra Harbor is not a safe haven. Under threatening conditions, all fleet units capable of evasion at sea should sortie at the earliest possible moment.

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NAVENVPREDRSCHFAC
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AN EVALUATION OF APRA HARBOR, GUAM AS A TYPHOON HAVEN

by

MICHAEL E. BROWN and SAMSON BRAND

NOVEMBER 1975

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY, CALIFORNIA 93940

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FOREWORD

COMSEVENTHFLT has requested that twenty-two western Pacific and Indian Ocean ports be evaluated as typhoon havens. CNO tasked COMNAVWEASERV with the preparation of these evaluations, and in response to a request from COMNAVWEASERV, COMNAVAIRSYSCOM tasked NAVENVPREDRSCHFAC with the development of these studies.

The present study of Guam represents one effort in the overall task, the final goal of which is a comprehensive typhoon havens handbook containing condensed studies for the twenty-two ports in the western Pacific/Indian Ocean.

The assistance of the Naval Weather Service Detachment, Asheville and the personnel of the Fleet Weather Central Guam, and Commander, Naval Forces Marianas in providing data, reports and comments is gratefully acknowledged.

R. C. SHERAR
Captain, U.S. Navy
Commanding Officer
Naval Environmental Prediction
Research Facility

CONTENTS

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LCDR Carl Hoffman who initiated the study on Guam, Mr. Jack Blelloch for compiling and reducing climatological data, Mr. Richard Clark for the graphics work, and Ms. Winona Carlisle for the typing.

1. INTRODUCTION

Severe tropical cyclones, also known as typhoons or hurricanes, are one of the most destructive weather phenomena a ship may encounter whether it be in port or at sea. When faced with an approaching tropical cyclone, a timely decision regarding the necessity and method of evasion must be reached. Basically, the question is: should the ship remain in port, evade at sea, or if at sea, should it seek the shelter offered by the harbor? This study will examine Apra Harbor, Guam to evaluate its potential as a typhoon haven.

In general it is an oversimplification to label a harbor as merely good or bad. Consequently, an attempt will be made to present enough information about the harbor to aid a commanding officer in reaching a sound decision with respect to his ship. The decision should not be based on the expected weather conditions alone, but also on the ship itself, as well as characteristics of the harbor. These characteristics include: natural shelter provided, port congestion, and support facilities (normal and emergency) available to individual type commands.

2. TROPICAL CYCLONES

2.1 DEVELOPMENT

Tropical cyclones are warm-core, nonfrontal low-pressure centers that develop over tropical or subtropical waters. Although the tropical cyclone formation process is not fully understood, it is well known that they require tremendous amounts of energy to develop and sustain the high wind velocities present. Only the warm moisture-laden air of the tropics possesses this quantity of energy. For this reason, tropical cyclones usually develop within 20° of the equator and begin to dissipate as they move into the cooler mid-latitudes.

2.2 WIND CIRCULATION

The wind circulation associated with tropical cyclones is counterclockwise about the eye in the Northern Hemisphere and clockwise in the Southern Hemisphere. Figure 1 depicts the wind pattern around the eye of a large, intense 150-kt typhoon. Note that the more intense winds are located in the right semicircle of the circulation. For this reason the right side of a tropical cyclone is known as the "dangerous semicircle."

The highest winds associated with tropical cyclones have never been accurately measured; however, based on data from past storms, tropical cyclone winds may attain speeds in excess of 150 kt. The following classification system concerning the intensity of tropical cyclones has been established by international agreement:

Tropical Depression:	Max sustained winds no greater than 33 kt
Tropical Storm:	Max sustained winds in the range 34-63 kt
Typhoon:	Max sustained winds in excess of 63 kt

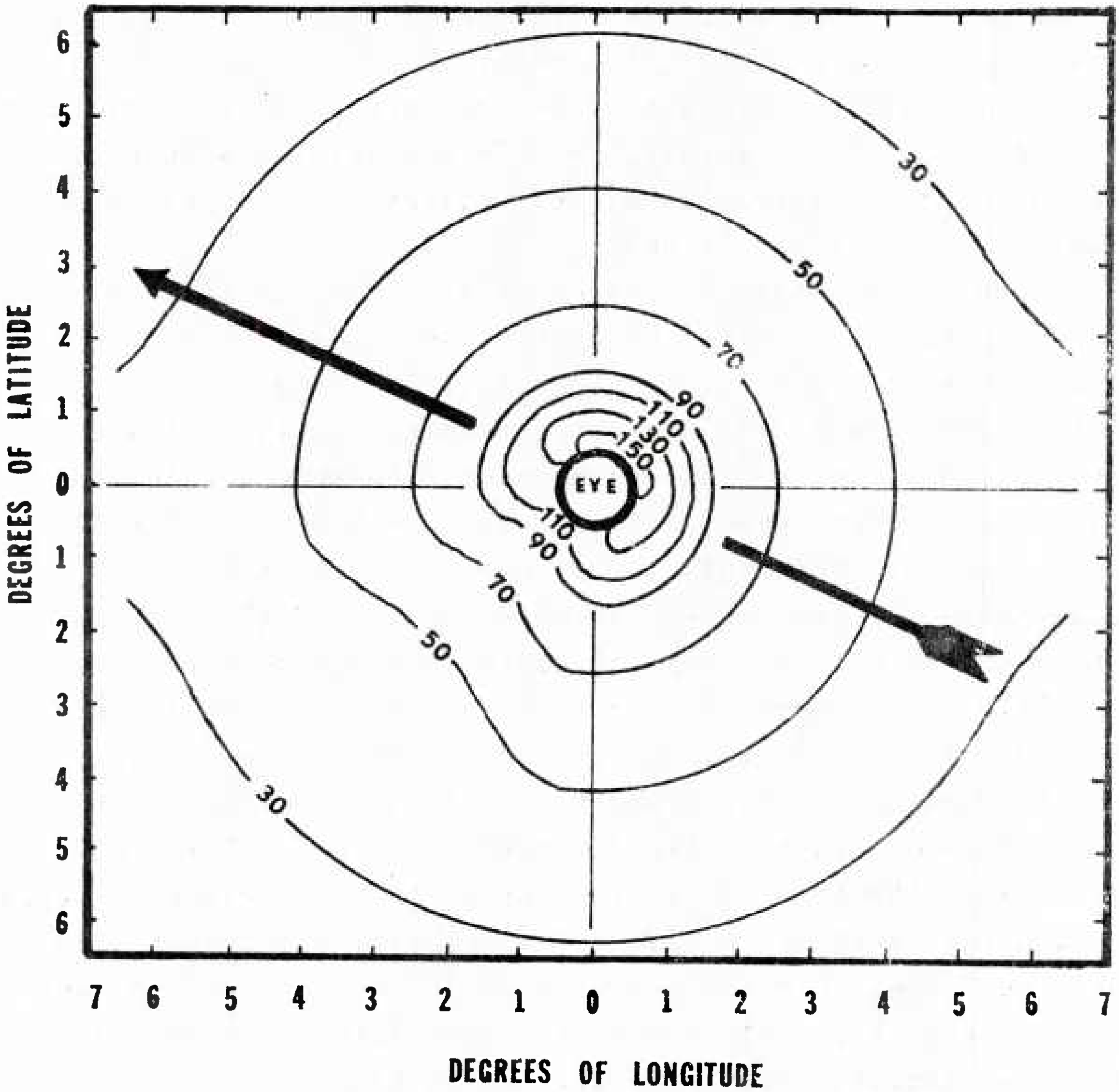

Figure 1. Distribution of surface wind speeds (in knots) around a large, intense typhoon in the northern hemisphere over open water. The arrow indicates direction of movement (after Harding and Kotsch, 1965).

2.3 MOVEMENT

The subject of tropical cyclone movement is very complicated since speed and direction of movement is primarily a function of wind and pressure patterns from the sea surface to the top of the atmosphere. In the initial stages of its development, the movement of a tropical cyclone is particularly difficult to forecast since the forecaster is dealing with an ill-defined circulation. This should be allowed for when warnings or formation alerts regarding newly developed tropical cyclones are issued.

Appendix A shows the tracks of all typhoons for the June-December period for the years 1946 through 1969. In these figures it can be seen that individual cyclones may follow erratic and widely varying tracks but, in general, they begin in the tropics and move west-northwest. In some cases the movement eventually becomes northward and finally northeastward. This shifting of direction is known as recurvature. Burroughs and Brand (1972) found that approximately 40% of WESTPAC tropical storms and typhoons recurved.

Prior to recurvature, tropical cyclones generally move at speeds from 8 to 14 kt; however, after recurvature they may accelerate and reach speeds 2-3 times the speed at the point of recurvature within 48 hours. (This acceleration varies with the time of year.) During the recurvature process the tropical cyclone is moving farther from the tropics; in doing so, comes into contact with cooler surface waters, and air from extratropical regions is drawn into its circulation. These two factors usually result in the tropical cyclone's ultimate weakening or dissipation.

2.4 SEA STATES AROUND TROPICAL CYCLONES

It is important to realize that sea conditions affecting ship movement will extend well beyond the wind field associated with a tropical cyclone, and that a miscalculation concerning sea conditions could result in a destructive rendezvous with the storm. The extent of the sea state generated by a tropical storm is primarily a function of storm size, duration and intensity. Figure 2 shows the combined sea height[1] associated with 21 WESTPAC tropical storms and typhoons (based on 173 analyses for the year 1971) plotted as a function of distance from the storm center and storm intensity (Brand, et al., 1973). There is a large variation in the sea state with storm intensity. A tropical storm (winds 34-63 kt) could produce 12-ft seas 217 n mi from the storm center; while an intense typhoon (winds $\geq$100 kt) could produce 12-ft seas 454 n mi from the center. The distances given are mean distances since the isopleths of combined sea height are not symmetric about the storm center. Brand, et al. (1973) found that the actual wave heights are at least partially dependent on the direction in which the storm is moving. For example, Figure 3 shows the average combined sea height isopleth pattern for storms moving on headings between 301° and 360° and is based on 66 sea-state analyses for tropical storms and typhoons that occurred during 1971. The mean speed of movement and mean wind speed for these analyses were 9.2 kt and 69.2 kt, respectively. Note that the greatest area of higher seas (9-15 ft range) exists to the rear and toward the right semicircle of the storm.

---

[1]The combined sea height is defined as the square root of the sum of the squares of "significant" sea and swell height. Sea is wind waves and swell consists of wind generated waves which have advanced into regions of weaker or calm winds. "Significant" will be defined here as the average height of the highest one-third of the waves observed over a specified time.

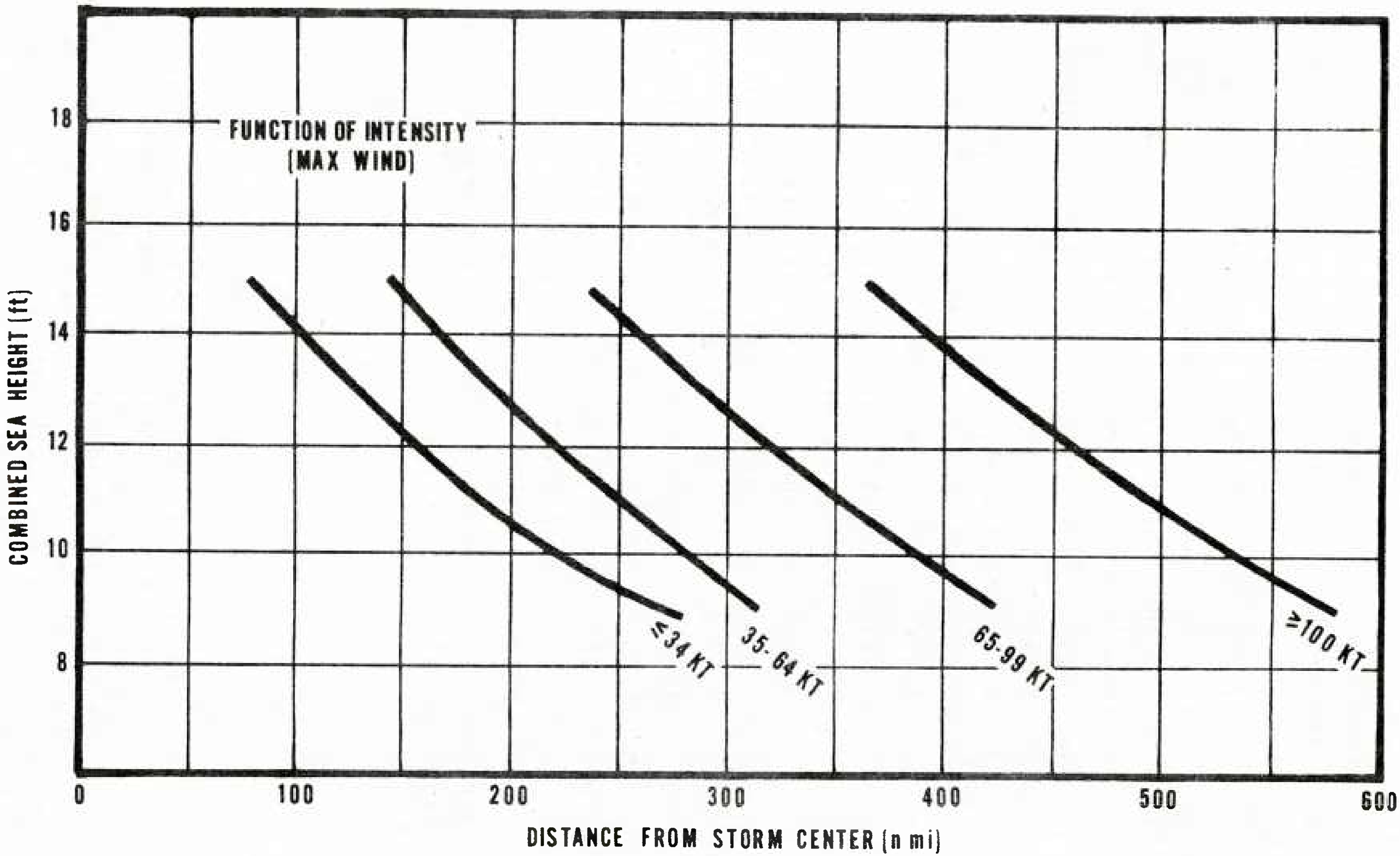

Figure 2. Combined sea height plotted against distance from storm center and given as a function of storm intensity (Brand, et al, 1973).

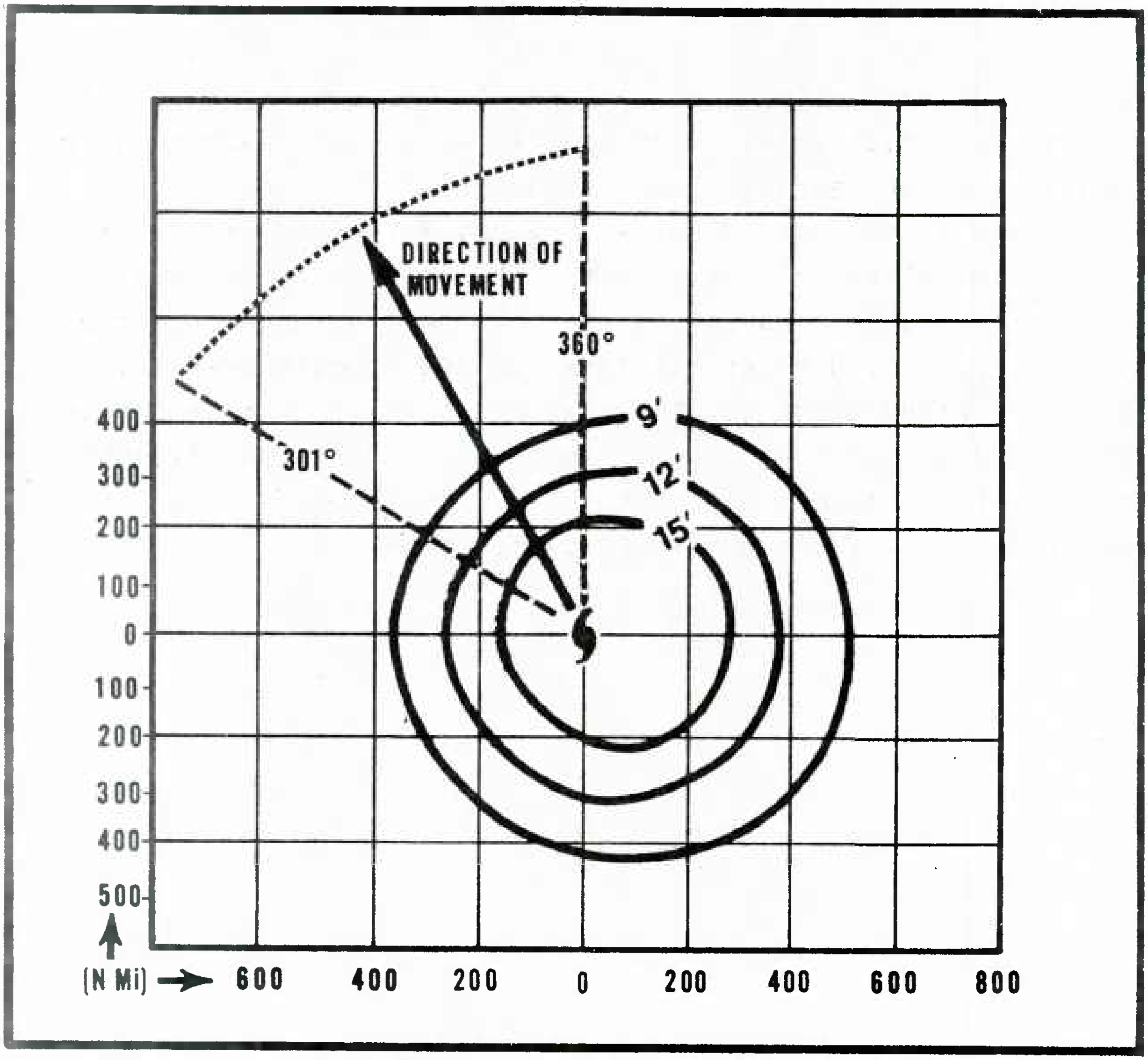

Figure 3. Combined sea-height isopleths (9-15 ft) based on 66 analyses of storms heading between 301°-360°. The mean speed of movement and mean wind speeds for these 66 analyses were 9.2 kt and 69.2 kt, respectively (after Brand et al., 1973).

3. GUAM

Figure 4 shows the western North Pacific area with Guam, the southernmost island in the Mariana Islands group, located approximately 1300 n mi east of the Philippines. Guam is a relatively flat island with only a few points reaching over 1000 feet above sea level (see Figure 5).

Agana is the capital city of Guam, with Apra Harbor as its commercial and military port. While other anchorages are available, Apra Harbor is the only port on Guam suitable for use by U. S. Navy or Military Sealift Command vessels.

A detailed study of the coast and bays of Guam is included in Hydrographic Office Publication No. 82 (formerly 165A). For specific comments on coastal features the reader is referred to the above mentioned publication.

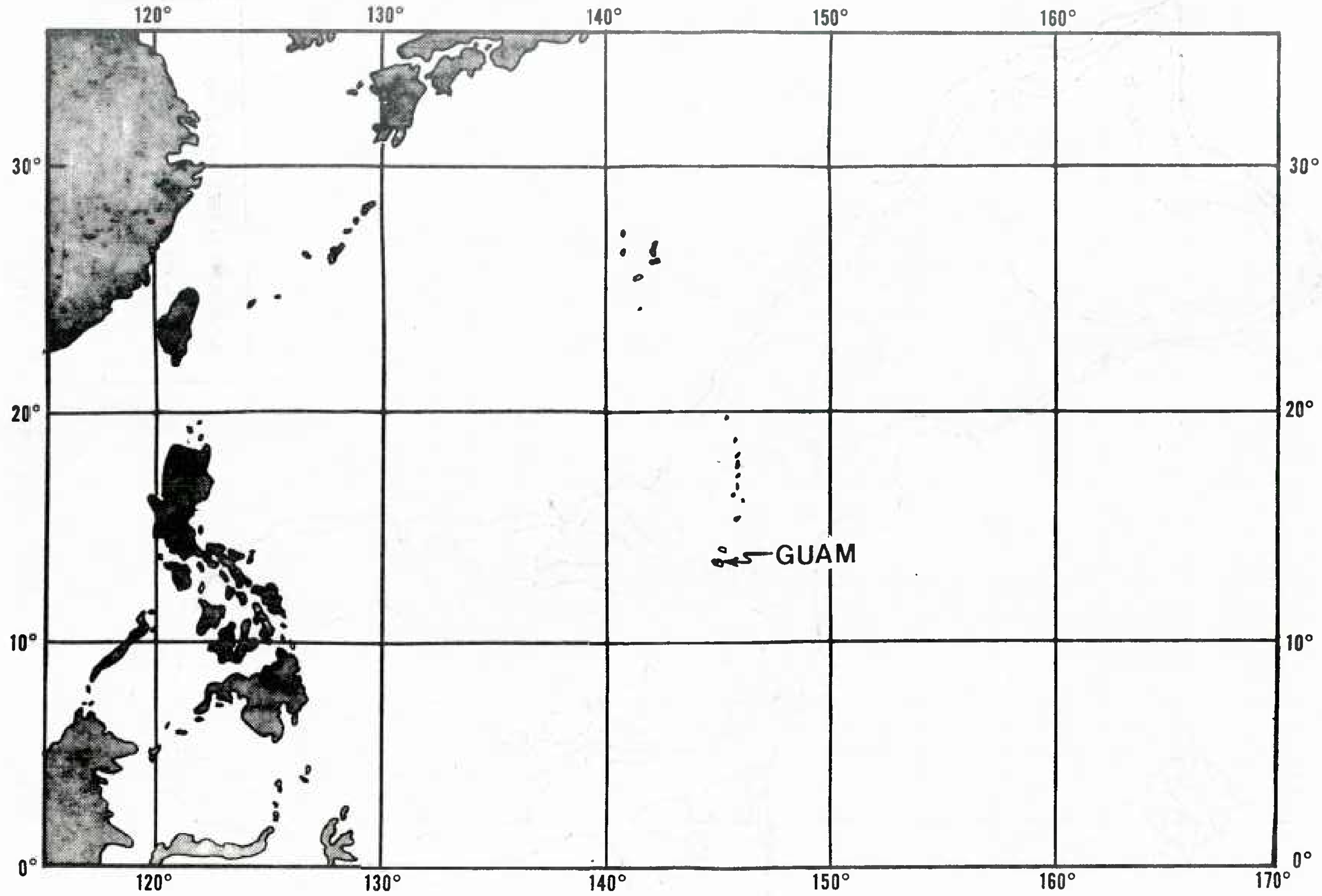

Figure 4. Map of the western North Pacific.

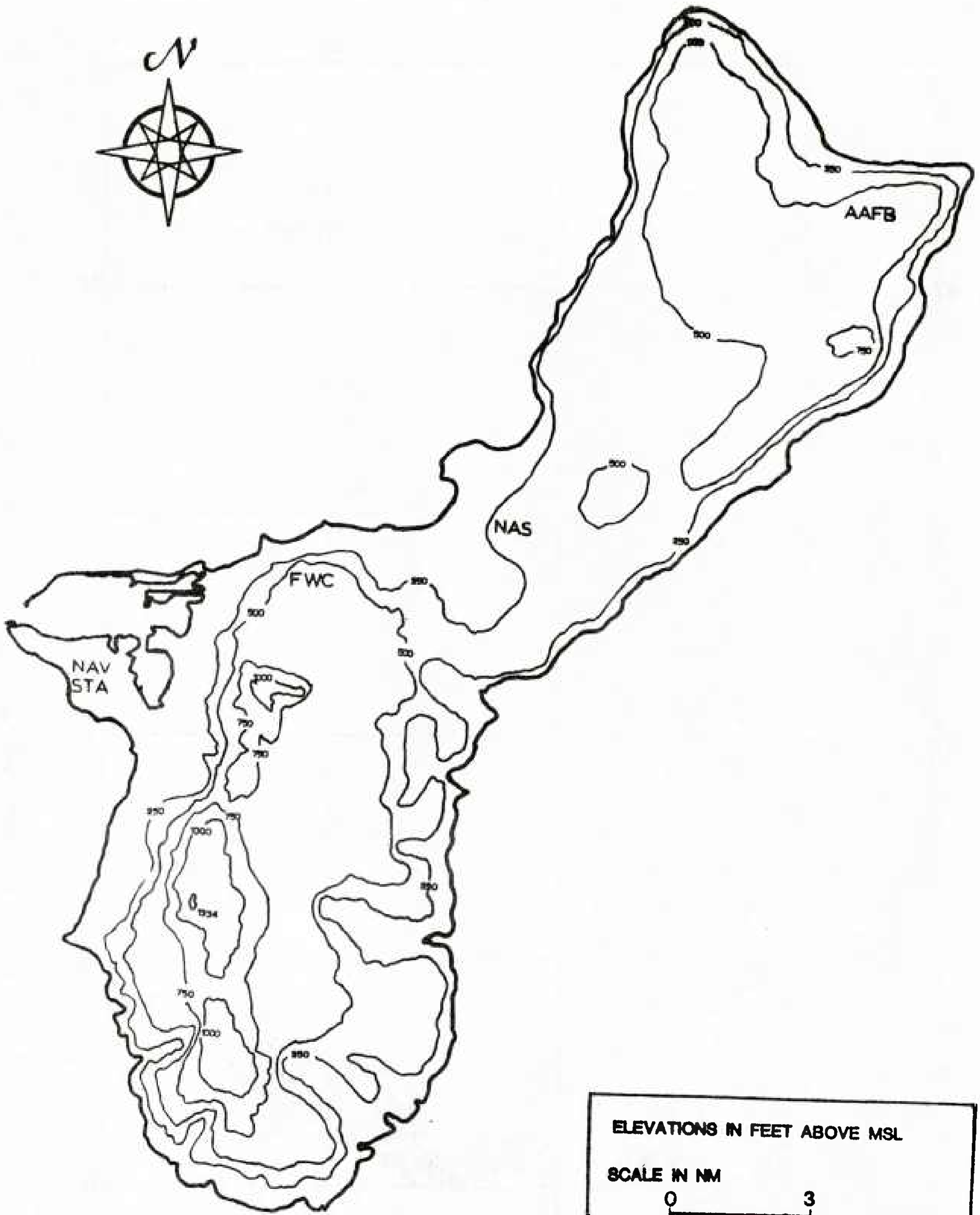

Figure 5. Topographical map of Guam.

4. APRA HARBOR

Apra Harbor, which consists of an inner and outer harbor, is an improved natural harbor located on the southwest coast of the island of Guam. Figure 6 shows the general harbor layout. Orote Peninsula which projects 3.5 n mi northwestward from the coast forms the southern boundary of the harbor. The harbor is bounded on the north by a breakwater that is partially man made and extends 15 ft (average) above mean sea level.

The entrance to Apra Harbor is 500 yards wide and in excess of 100 ft deep. Apra Harbor is extensive and contain a substantial number of mooring buoys and piers. The outer harbor affords a large number of deep water anchorages and the holding capacity is considered excellent. Appendix C contains a list of all harbor facilities including details as to type and capacity. It should be noted that the outer harbor contains several shoal or reef areas that are clearly marked. While these areas pose only a limited threat to normal operations, they must be a major consideration should maneuvering be required during periods of heavy weather.

The low hills to the east of Apra Harbor provide a windbreak for easterly winds. However, Apra Harbor should by no means be considered a sheltered port.

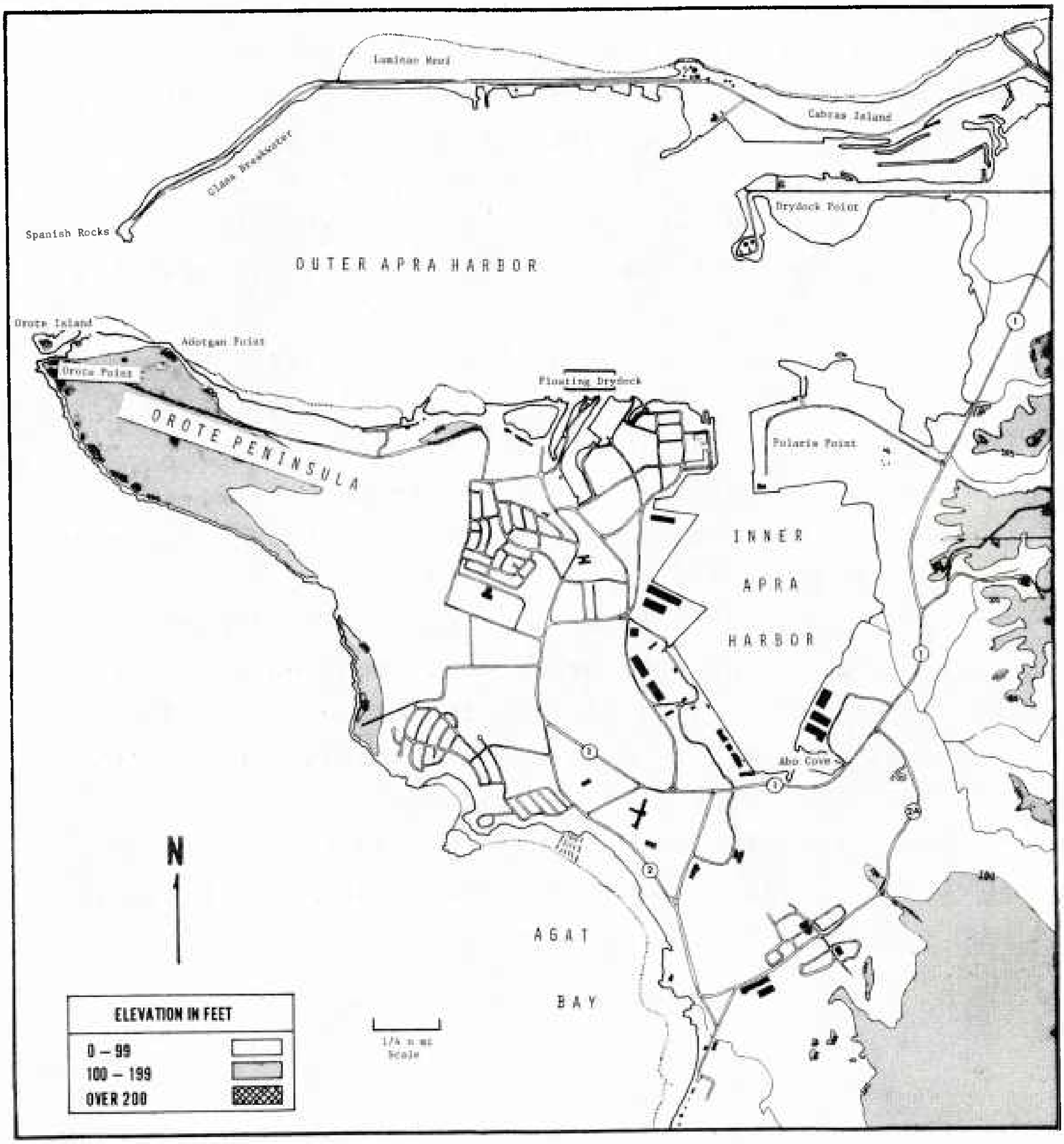

Figure 6. Apra Harbor

5. TROPICAL CYCLONES AFFECTING GUAM

5.1 CLIMATOLOGY

Severe tropical cyclones can occur during any month of the year in the western North Pacific area. However, the majority of those that pose a "threat" to Guam (any tropical cyclone approaching within 180 n mi is considered a "threat") occur during the months June-December. Figure 7 gives the monthly summary of threat situations by 5-day periods, based on June-December data for the 27 years, 1947 to 1973. Note the maximum number of storms occur in the months July through November.

In Figure 8 these "threat" tropical cyclones are displayed according to the compass octant from which they approached Guam. The circled numbers indicate the total that approached from an individual octant. The numbers in parentheses give this as a percentage of the total. It is readily seen that a majority of storms approach from the east and southeast.

Approximately 4 tropical cyclones each year will pose a threat to Guam. Since Guam is in the development area for WESTPAC tropical cyclones many of these storms are in the formative stages of their life cycle and have not, as yet, achieved typhoon intensity. Of the 107 tropical cyclones that approached or developed within 180 n mi of Guam in the period June-December, 1947 to 1973, the point where these storms attained tropical storm intensity ($\geq$34 kt) is in many cases to the west of Guam (see Figure 9). In fact approximately 50% reach tropical storm intensity after their Closest Point of Approach (CPA) (assuming most were heading on a general east to west track).

Figure 10 shows the point at which the tropical cyclones reached typhoon intensity ($\geq$64 kt). Notice that about 75% of the typhoons attained typhoon intensity to the west of Guam.

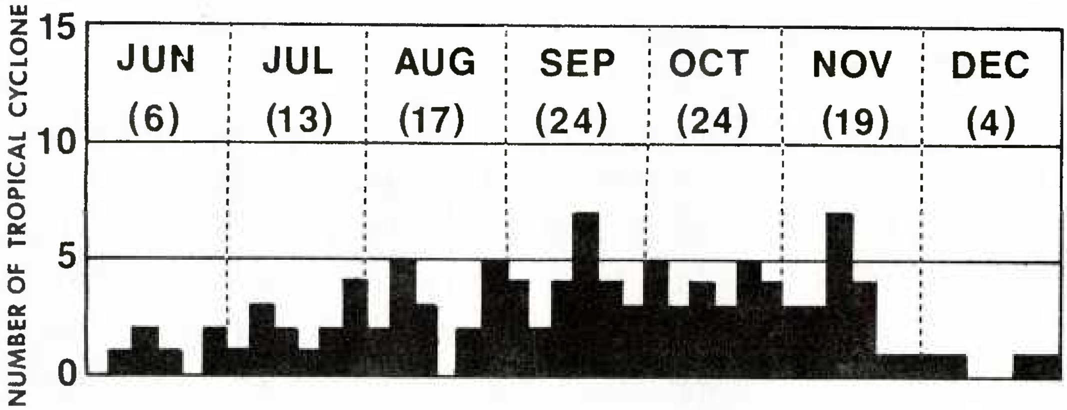

Figure 7. Frequency distribution of the number of tropical cyclones that passed within 180 n mi of Guam (June-December, 1947-1973). Subtotals are based on 5-day periods and the numbers in parentheses are the monthly totals.

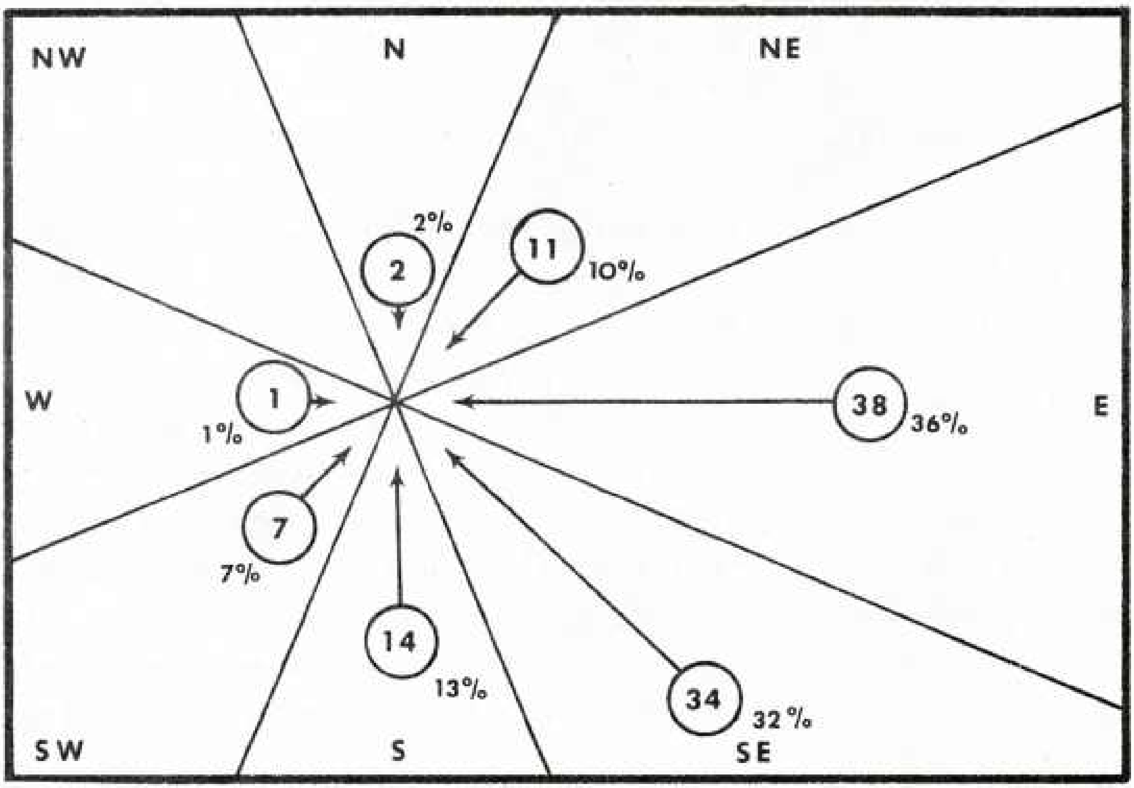

Figure 8. Direction of approach to Guam of the tropical cyclones (June-December, 1947-1973) which passed within 180 n mi of Guam. Circled numbers indicate the number that approached from each octant. The numbers in parentheses are the percentage of the total sample (107) that approached from that octant.

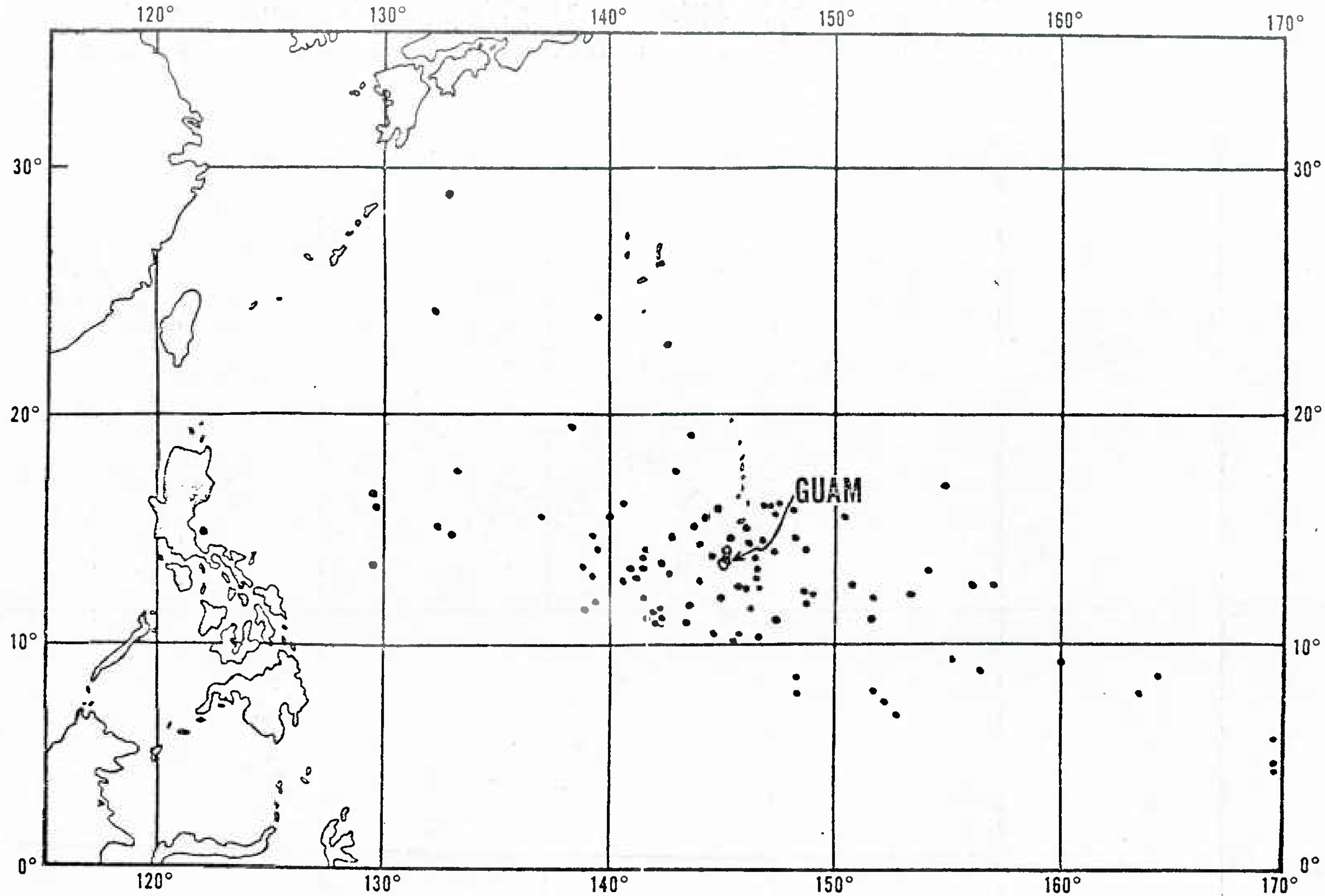

Figure 9. Initial point of attainment of tropical storm intensity ($\geq$ 34kt) for 107 tropical cyclones passing within 180 n mi of Guam (June-December, 1947-1973). Since 7 tropical depressions did not achieve the above ciriteia, only 100 positions are plotted.

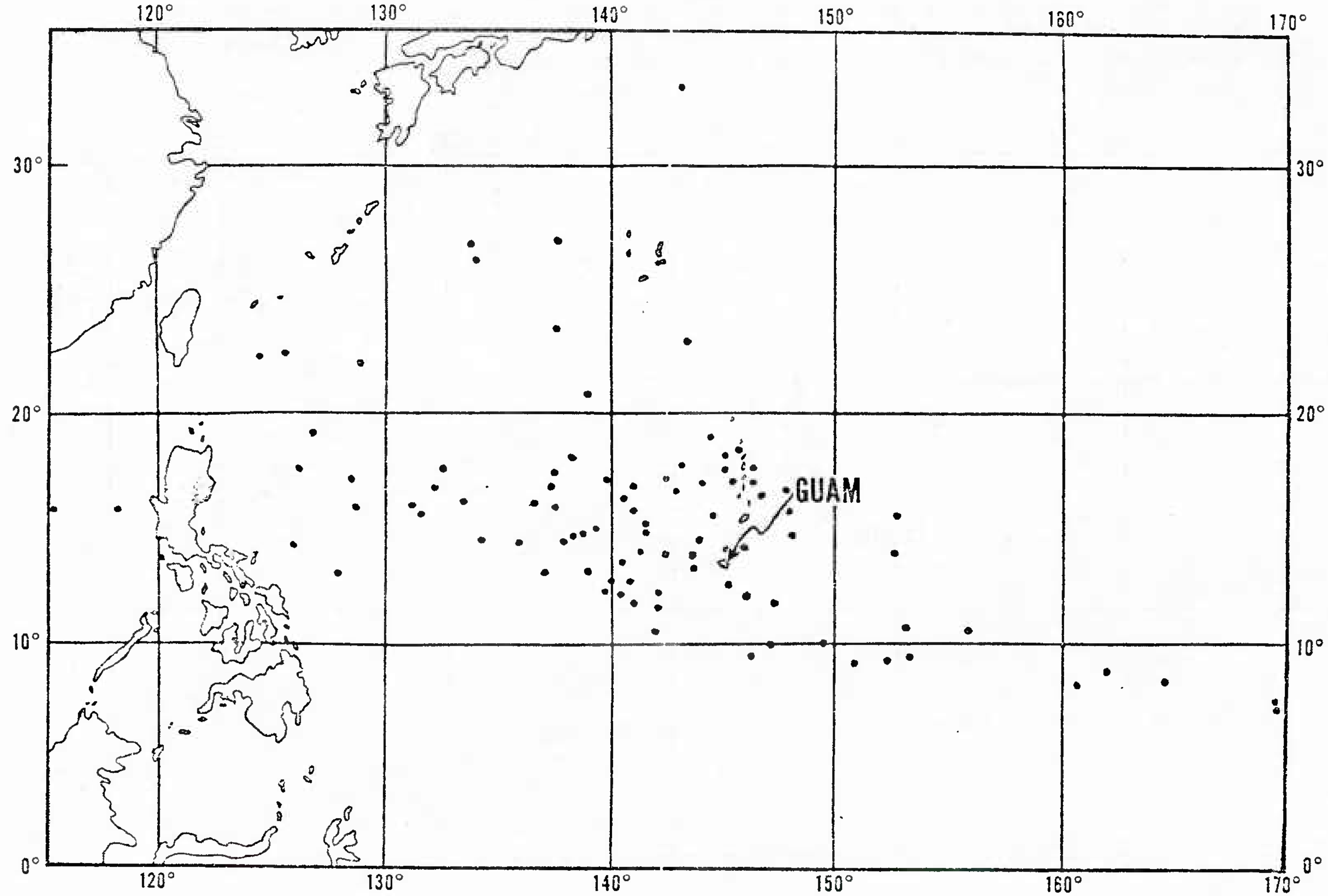

Figure 10. Initial point of attainment of typhoon intensity ($\geq$ 64kt) for 107 tropical cyclones passing within 180 n mi of Guam (June-December, 1947-1973). Since 16 tropical cyclones did not achieve the above criteria, only 91 positions are plotted.

The fact that a large percentage of storms are not of "typhoon" intensity at CPA must not allow the reader to develop a false sense of security. While a storm with winds of 50-60 kt is obviously not a typhoon, the potential for damage is still very significant.

A tropical cyclone in the vicinity of Guam will, on the average, intensify 15-20 kt/24 hr, but the danger always exists that the storm will rapidly intensify by 40-50 kt/ 24 hr (5-10% probability for this region).

As an overview of the climatology involved, Figures 11 to 17 show a statistical summary based on tropical cyclone tracks for the years 1947-1973.[2] The data are grouped by months, June-December. Since tracks were recorded for 5-day periods, exact calendar months could not be used (see legend). In these figures, the total number of storms that passed through each 3° lat/long square for a given month, defined as N, is printed at the top of each square. At the bottom of each square is a number (defined as "RAD") representing the percent of those tropical cyclones that passed through the square and subsequently passed within 180 n mi of Guam. To further assess the threat to Guam, the parameters L_1, L_3, R_1, and R_3 are defined as:

R_1: Percentage of all tropical cyclones that passed through the box and subsequently crossed the line to the north of Guam within a distance of 60 n mi (1° latitude).

R_3: Percentage of all tropical cyclones that passed through the box and subsequently crossed the line to the north of Guam within a distance of 180 n mi (3° latitude).

---

[2]From Chin, 1972 for years 1947-70, and from FWC/JTWC Annual Typhoon Reports for 1971-1973.

L_1: Percentage of all tropical cyclones that passed through the box and <u>subsequently</u> crossed the line to the south of Guam within a distance of 60 n mi (1° latitude).

L_3: Percentage of all tropical cyclones that passed through the box and <u>subsequently</u> crossed the line to the south of Guam within a distance of 180 n mi (3° latitude).

These are printed at the left and right edges of the 3° squares. These above parameters are significant in that the effect a tropical cyclone has on a harbor is a function of relative positions of storm and harbor during passage. For example, in Figure 13 the 3° square located between 147°E and 150°E, 9°N and 12°N had 6 tropical cyclones pass through it during the years 1947-1973. Of these, 83% (5 of the 6 tropical cyclones), subsequently approached within 180 n mi of Guam. Of the 6 tropical cyclones 33% passed within 60 n mi to the north and 33% within 180 n mi to the north; 17% passed within 60 n mi to the south and 33% within 180 n mi to the south.[3]

In Figures 18 to 24 the 1947-1973 statistics have been reanalyzed using the RAD numbers. The solid lines present a "percent threat" figure for any storm location. The dashed lines represent approximate approach times to Guam based on an approach speed of 8-12 kt. For example, in Figure 18 a storm located at 150°E and 8°N has an 80% probability of passing within 180 n mi of Guam and, if its speed remains in the 8-12 kt range, it will reach Guam in slightly over 1½-2 days (the faster the speed of an individual storm the shorter the time required to reach Guam).

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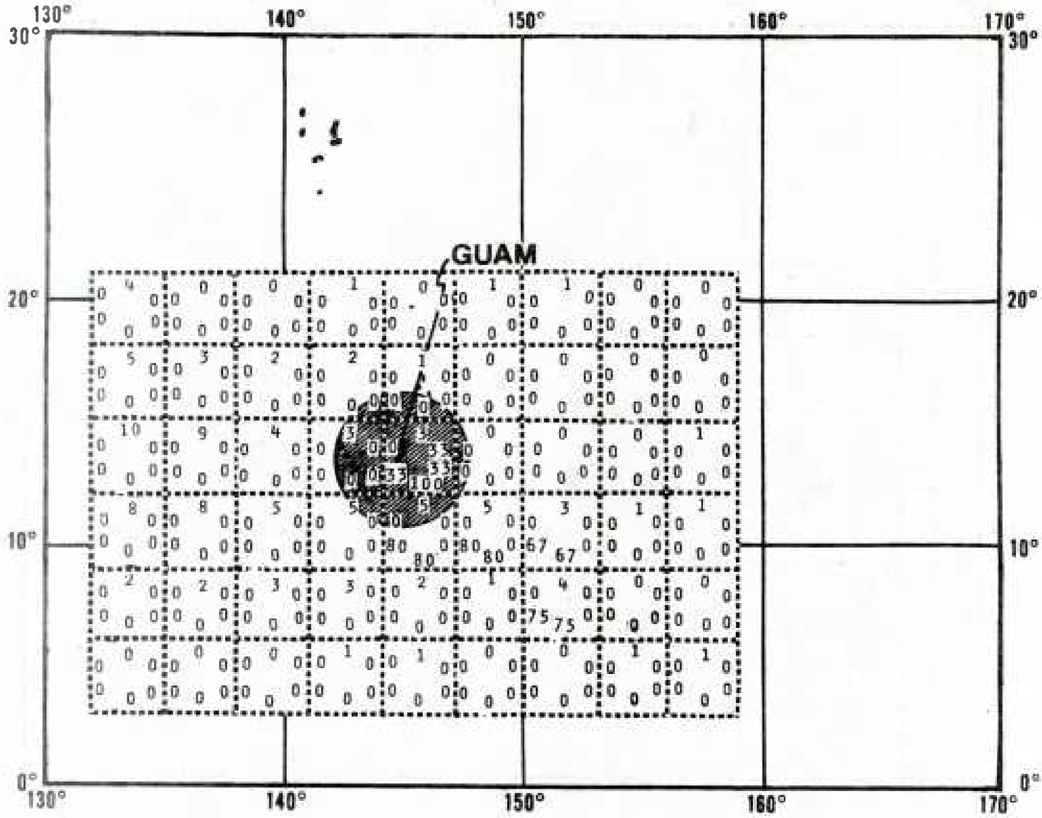
[3]Note that $R_3 + L_3$ need not equal RAD since a storm may enter the 180 n mi circle but not cross the N-S line.



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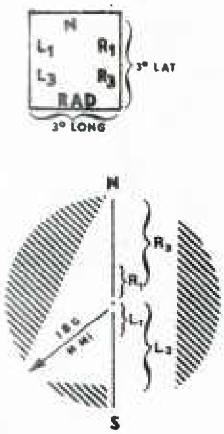


N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

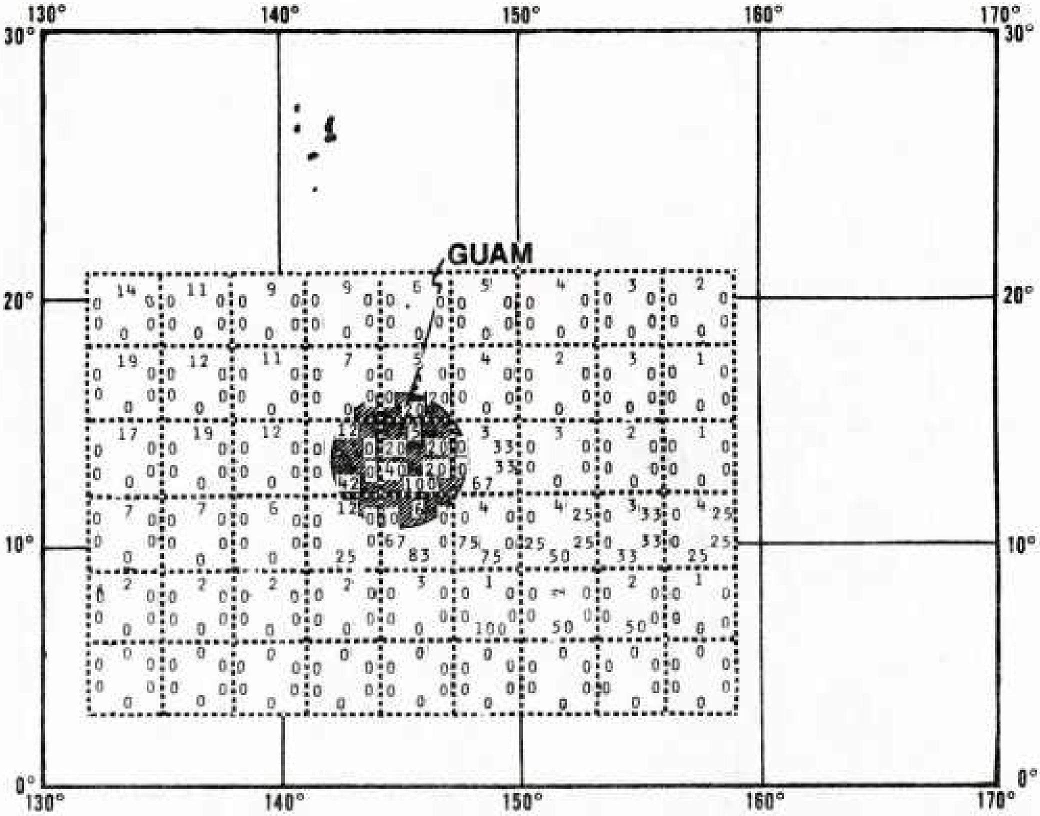
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

FOR THE MONTH OF:

JUN

Figure 11. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of June. (Based on data from 1947-1973.)



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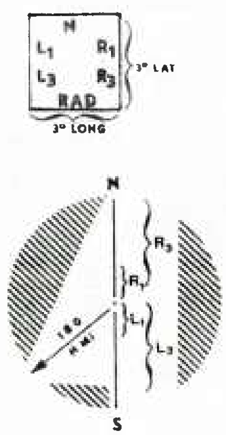

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L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

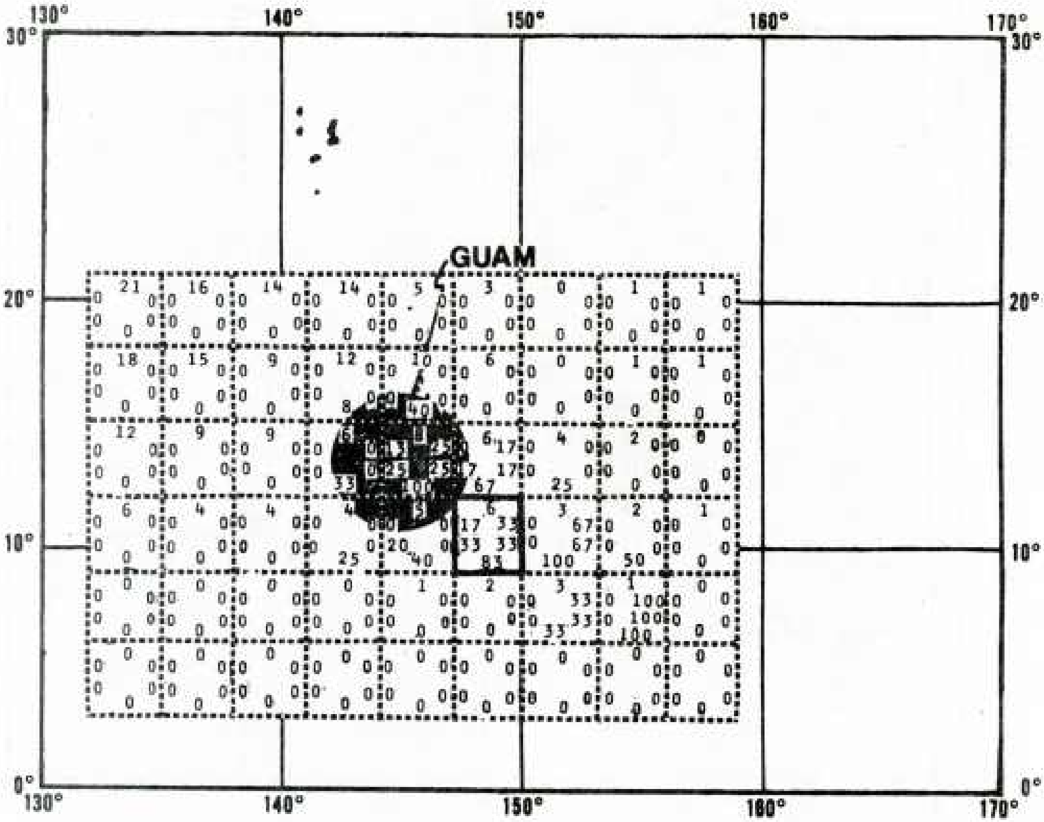
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

FOR THE MONTH OF:

JUL

Figure 12. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of July. (Based on data from 1947-1973.)



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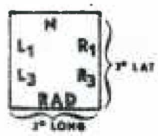
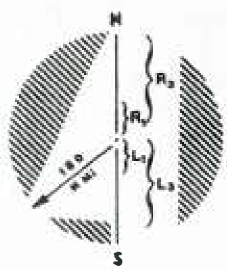




N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

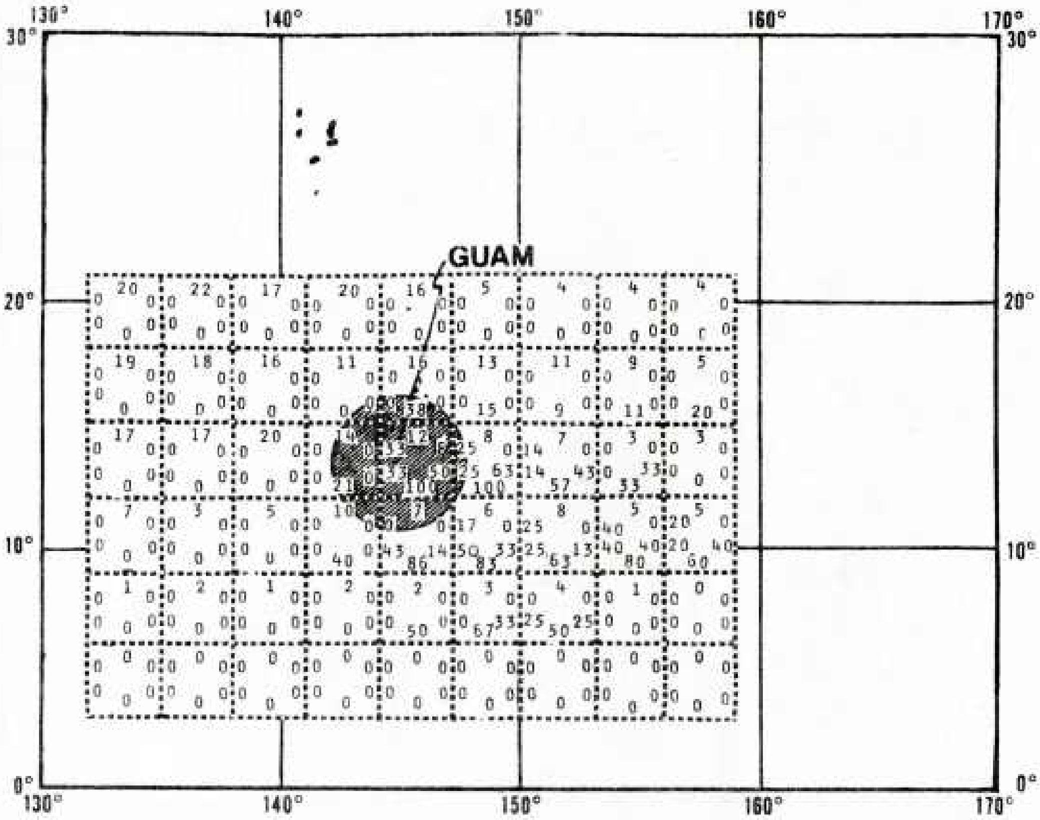
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

FOR THE MONTH OF:

AUG

Figure 13. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of August. (Based on data from 1947-1973.)



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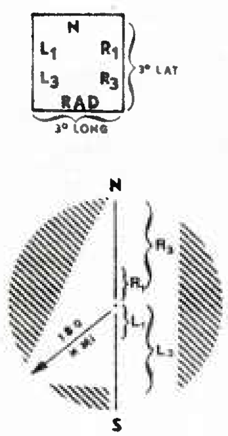


N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

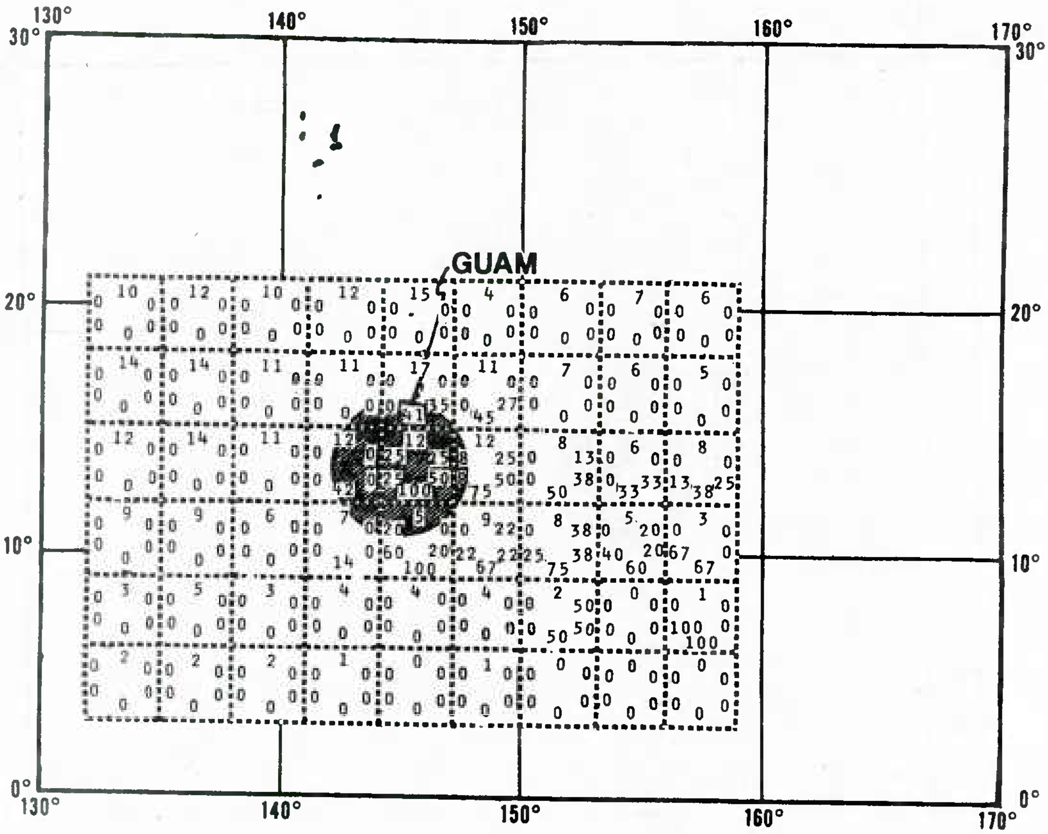
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

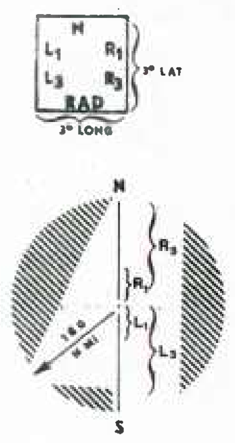
FOR THE MONTH OF:

SEP

Figure 14. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of September. (Based on data from 1947-1973.)



LEGEND:



N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

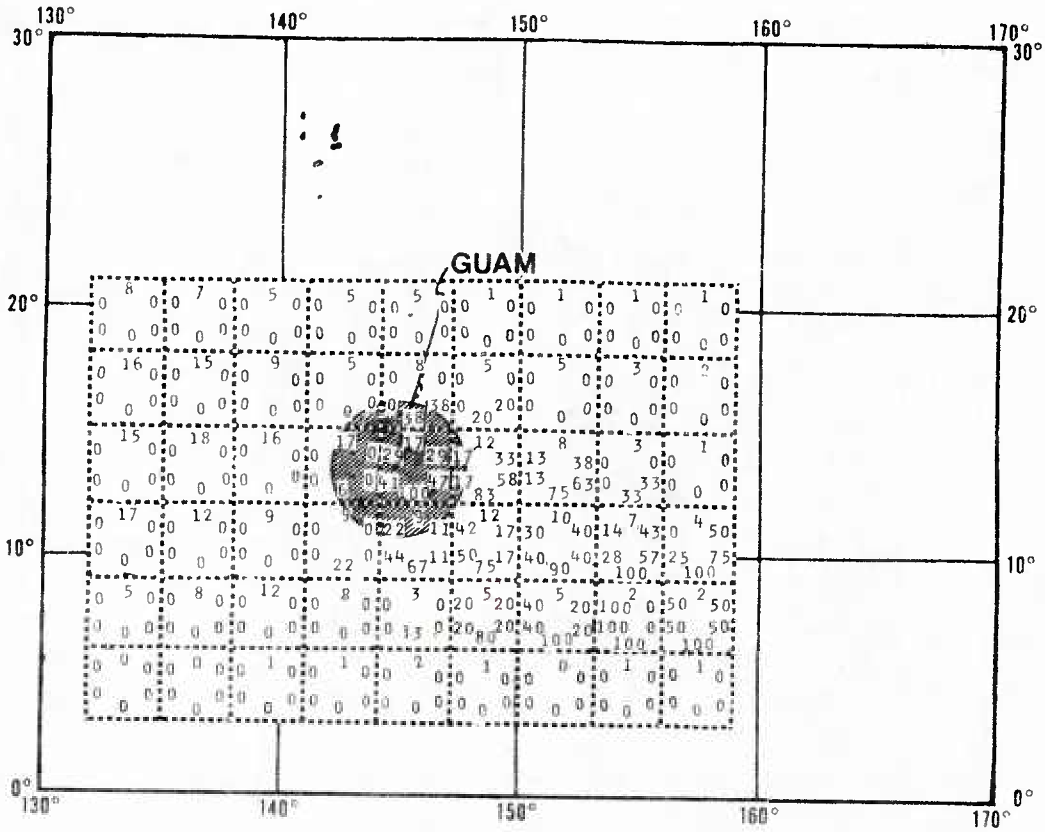
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

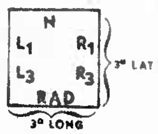
FOR THE MONTH OF:

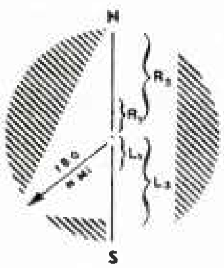
OCT

Figure 15. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of October. (Based on data from 1947-1973.)



LEGEND:





N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

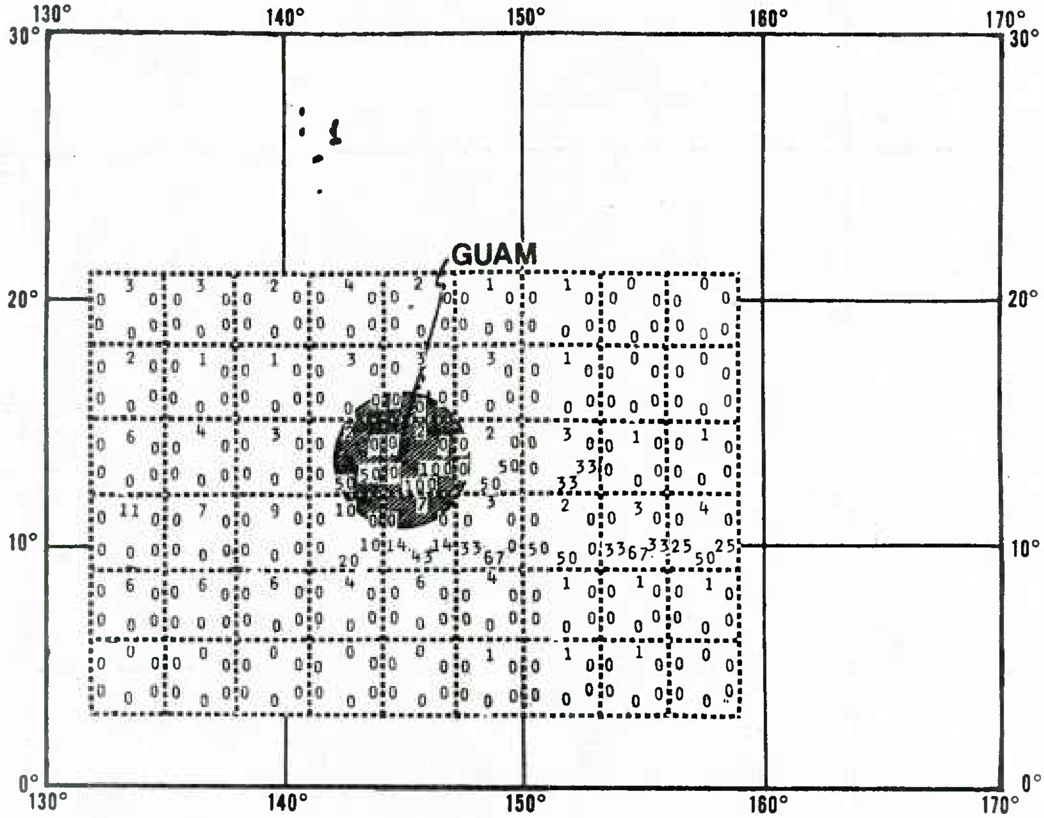
R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

FOR THE MONTH OF:

NOV

Figure 16. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of November. (Based on data from 1947-1973.)



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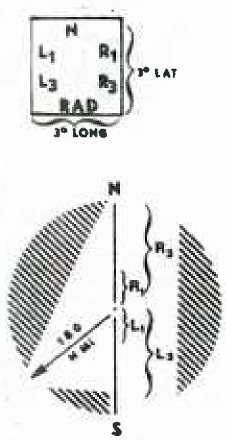

N = NUMBER OF TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE FOR THE MONTH

L_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

L_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING SOUTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

R_1 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 60 N MI (1° LAT)

R_3 = PERCENT OF ALL TROPICAL CYCLONES THAT PASSED THROUGH THIS SQUARE AND SUBSEQUENTLY CROSSED A LINE EXTENDING NORTH FROM GUAM WITHIN A DISTANCE OF 180 N MI (3° LAT)

RAD = PERCENT OF TROPICAL CYCLONES THAT PASSED THROUGH THE SQUARE AND SUBSEQUENTLY PASSED WITHIN 180 N MI OF GUAM

FOR THE MONTH OF:

DEC

Figure 17. Statistical summary of tropical cyclone tracks that passed within 180 n mi of Guam for the month of December. (Based on data from 1947-1973.)

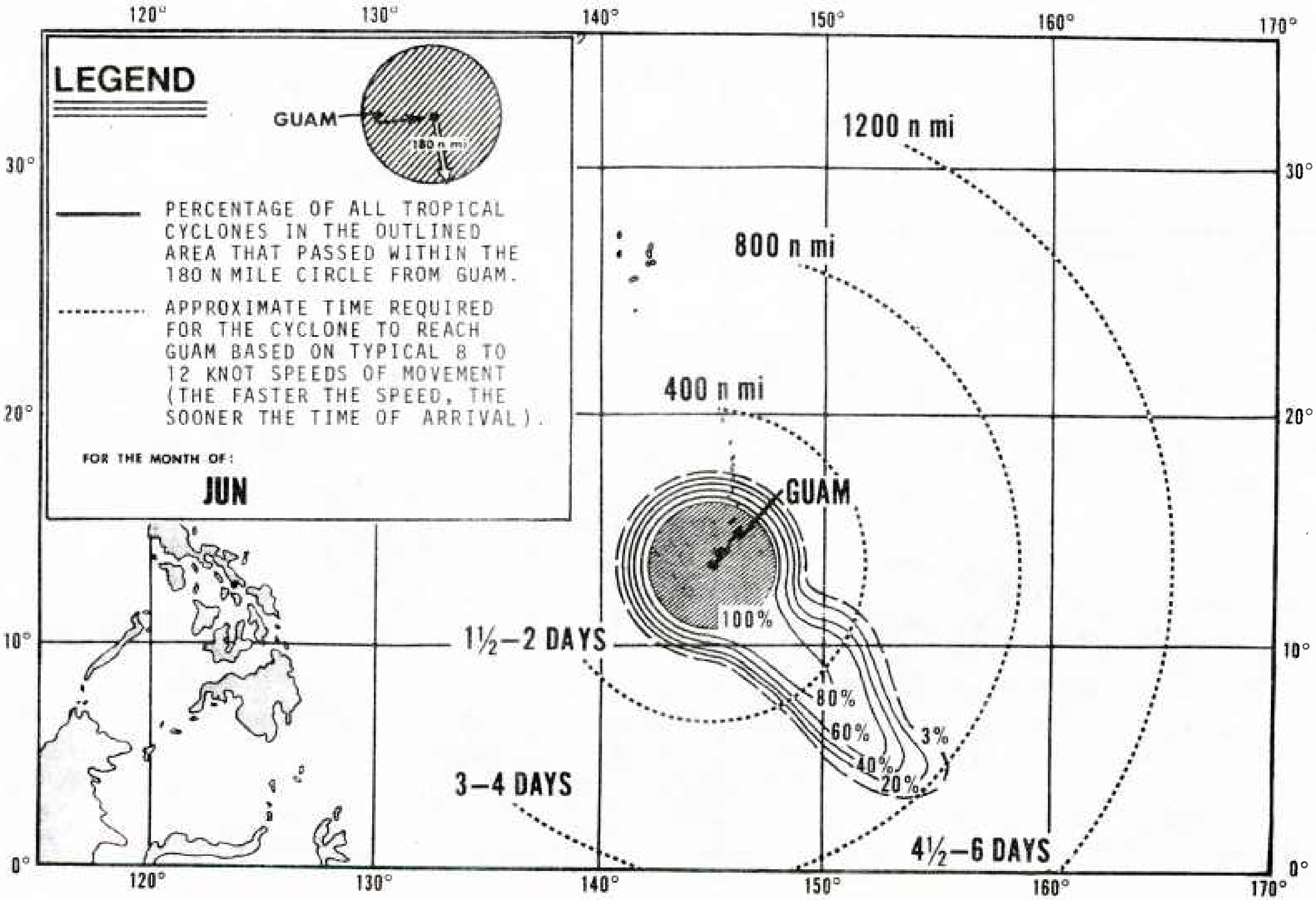

Figure 18. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of June. (Based on data from 1947-1973.)

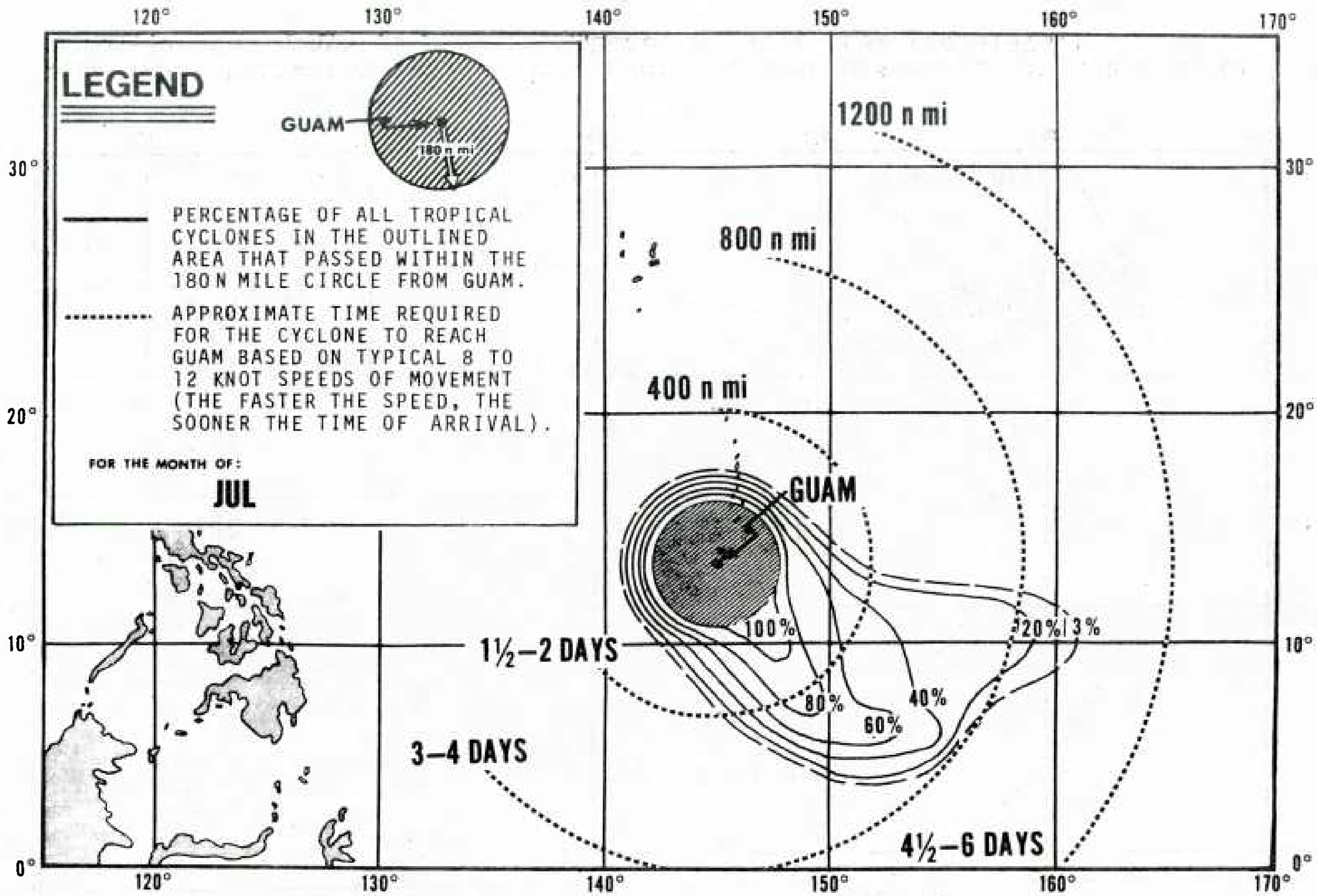

Figure 19. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of July. (Based on data from 1947-1973.)

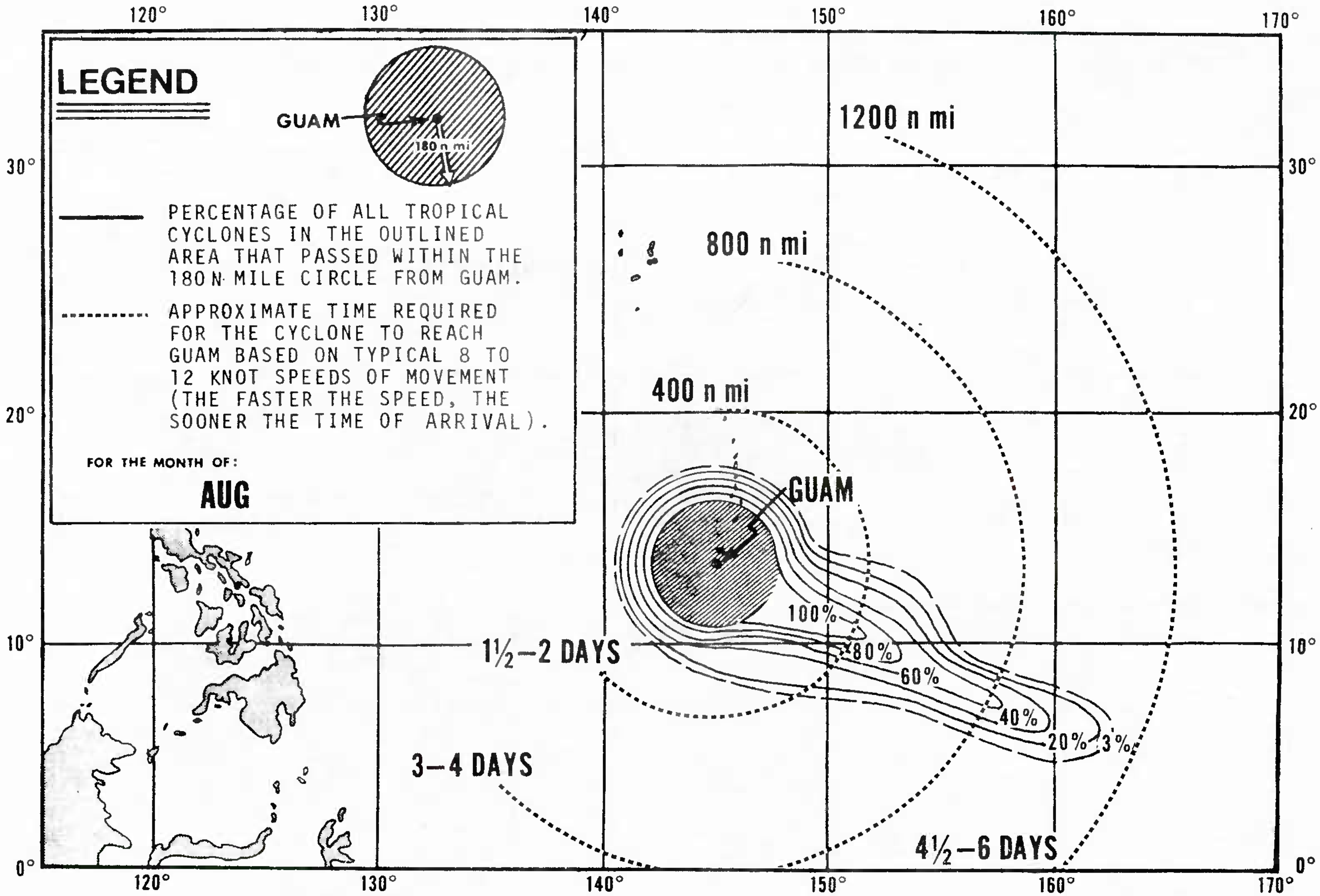

Figure 20. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of August. (Based on data from 1947-1973.)

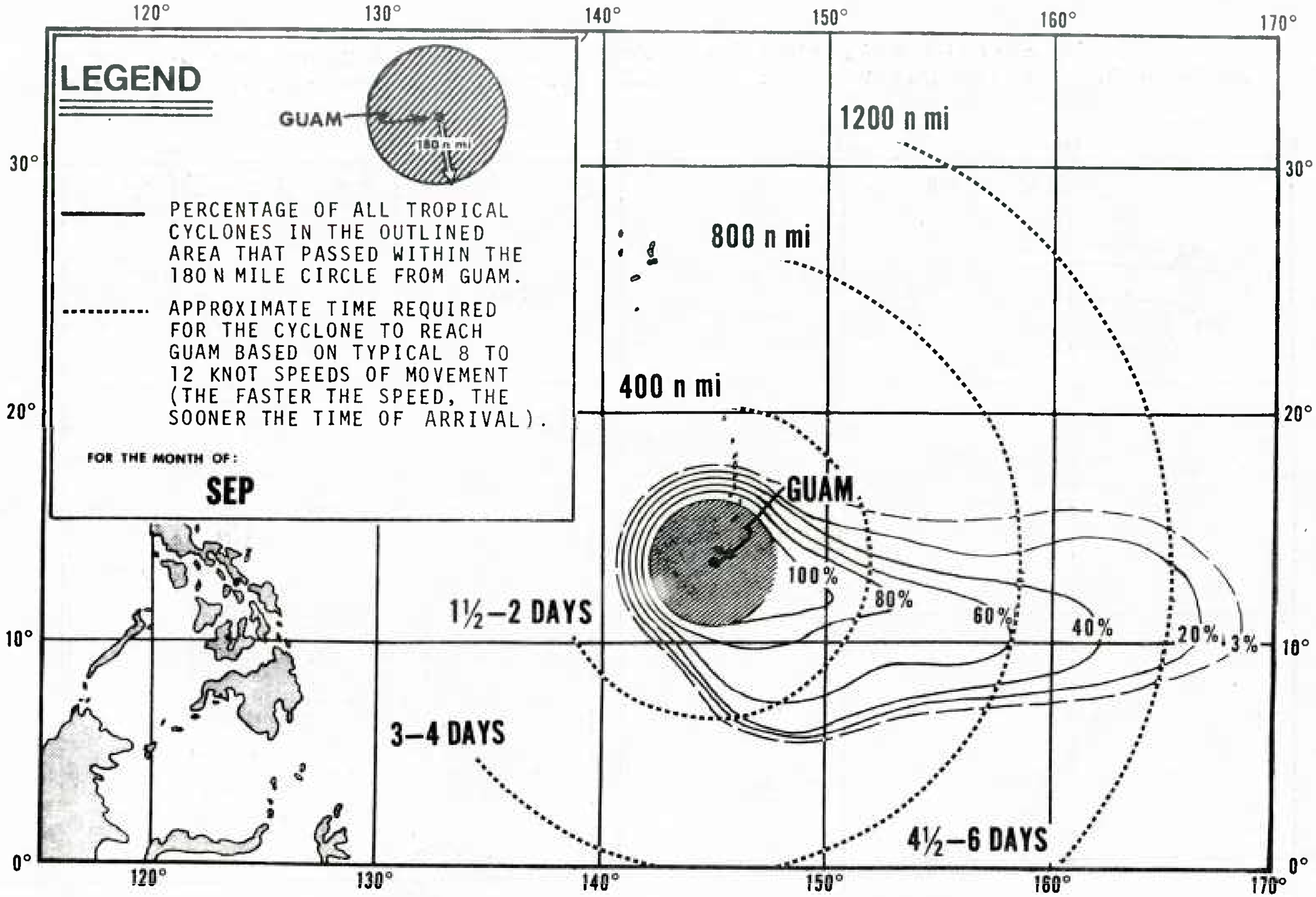

Figure 21. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of September. (Based on data from 1947-1973.)

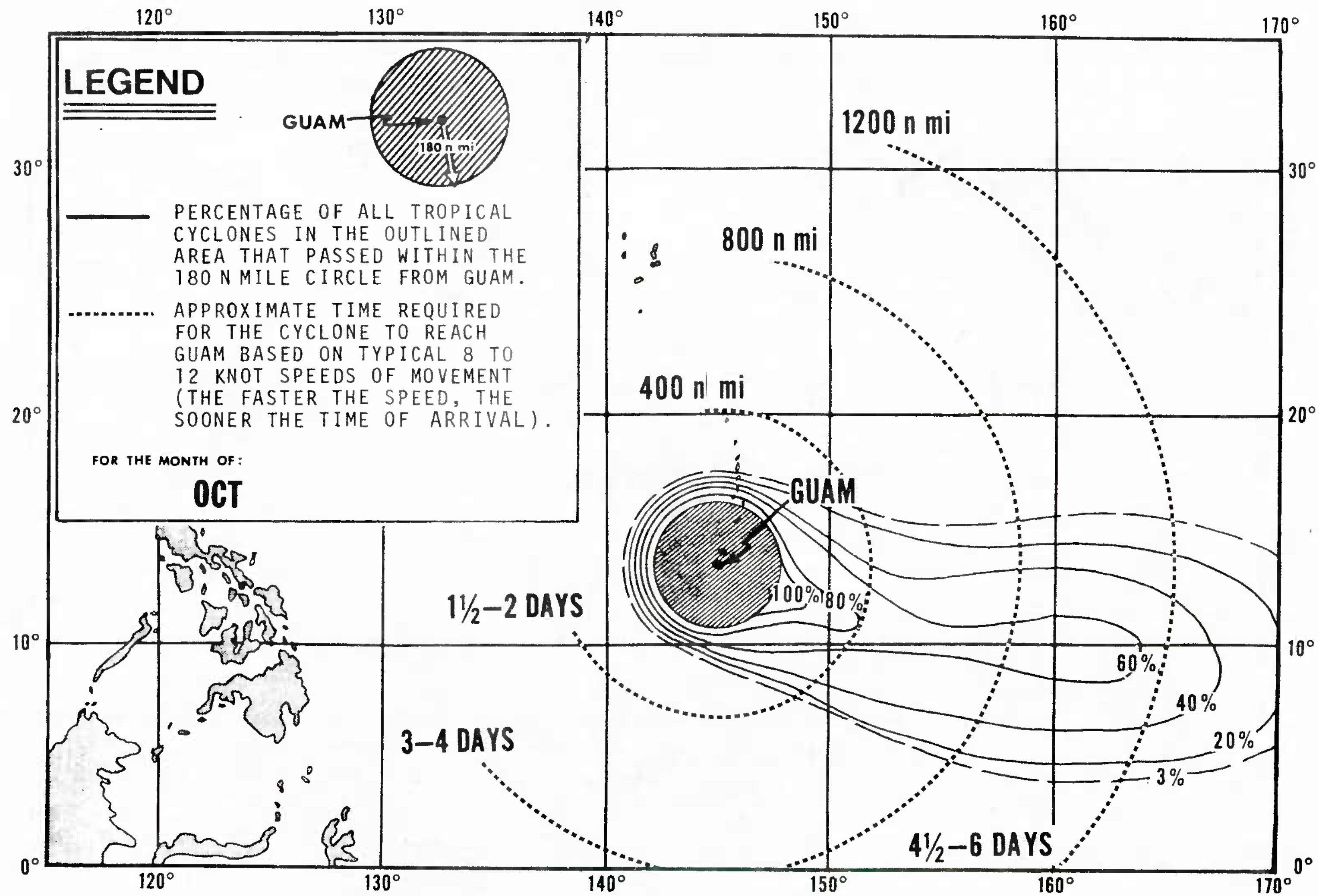

Figure 22. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of October. (Based on data from 1947-1973.)

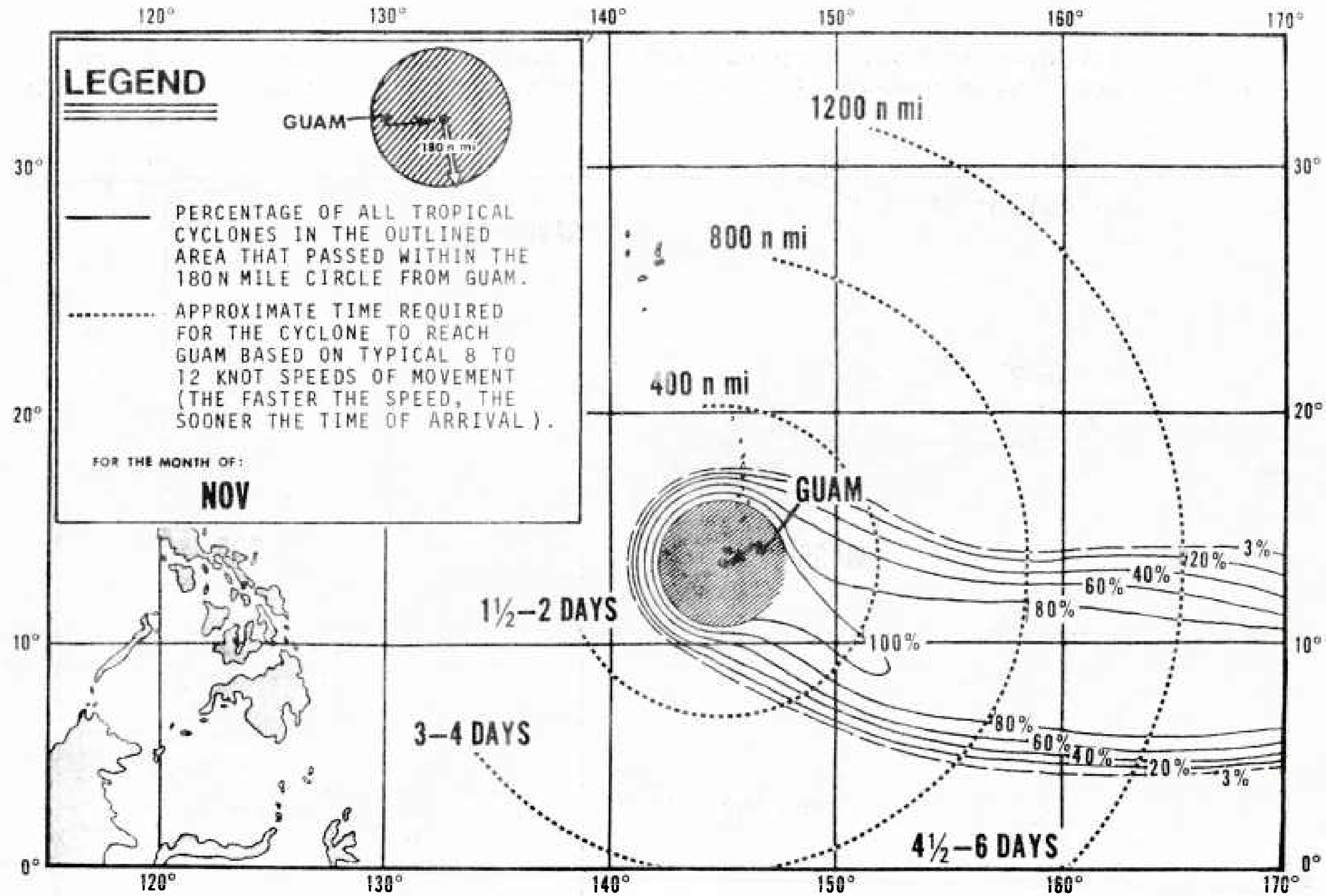

Figure 23. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of November. (Based on data from 1947-1973.)

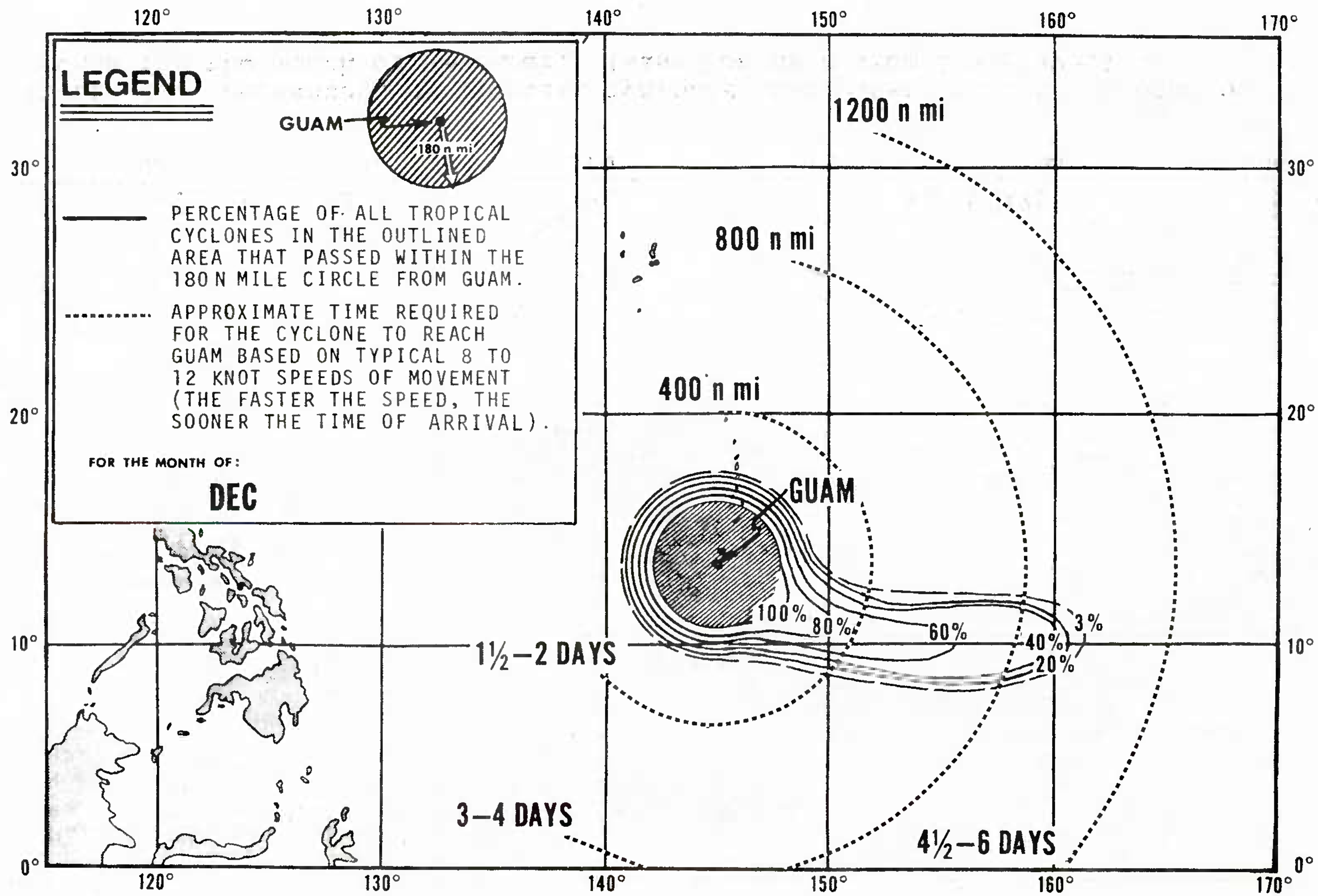

Figure 24. Percentage of tropical cyclones that passed within 180 n mi of Guam for the month of December. (Based on data from 1947-1973.)

For the remainder of this section, only those tropical cyclones that passed within 180 n mi (3° of latitude) of Guam will be considered. It is realized that storms which did not approach within this limit may have affected the harbor. However, a criterion had to be chosen that would limit the data sample; 180 n mi was the limit selected.

In the 27 years 1947-1973 (considering the months June through December), an average of four tropical cyclones per year passed within 180 n mi of Guam (107 total). The largest number that occurred in any single year was seven (1958, 1965, and 1971). In Table 1, the 107 storms which passed within 180 n mi, are grouped according to their effect at Guam.[4] It can be seen that of the total 107, only 34 storms (approximately 32%) resulted in winds of 22 kt or greater at Guam. Only 8 tropical cyclones (7%) resulted in gale force winds or greater (≥34 kt).

Table 1. Extent to which tropical cyclones affected Guam (NAS Agana) during the period June-December, 1947-1973.

Number of storms that passed within 180 n mi of Guam	107
Number of storms that resulted in winds ≥22 kt at Guam	34
Number of storms that resulted in winds ≥34 kt at Guam	8

Figure 25 shows the tracks of the 8 gale associated storms. When the tracks in Figure 25 are compared with the mean tracks in Appendix A, it becomes apparent that the

[4]Wind information is based on hourly wind observations from Naval Air Station, Agana, which is felt to be representative of the winds experienced in Apra Harbor.

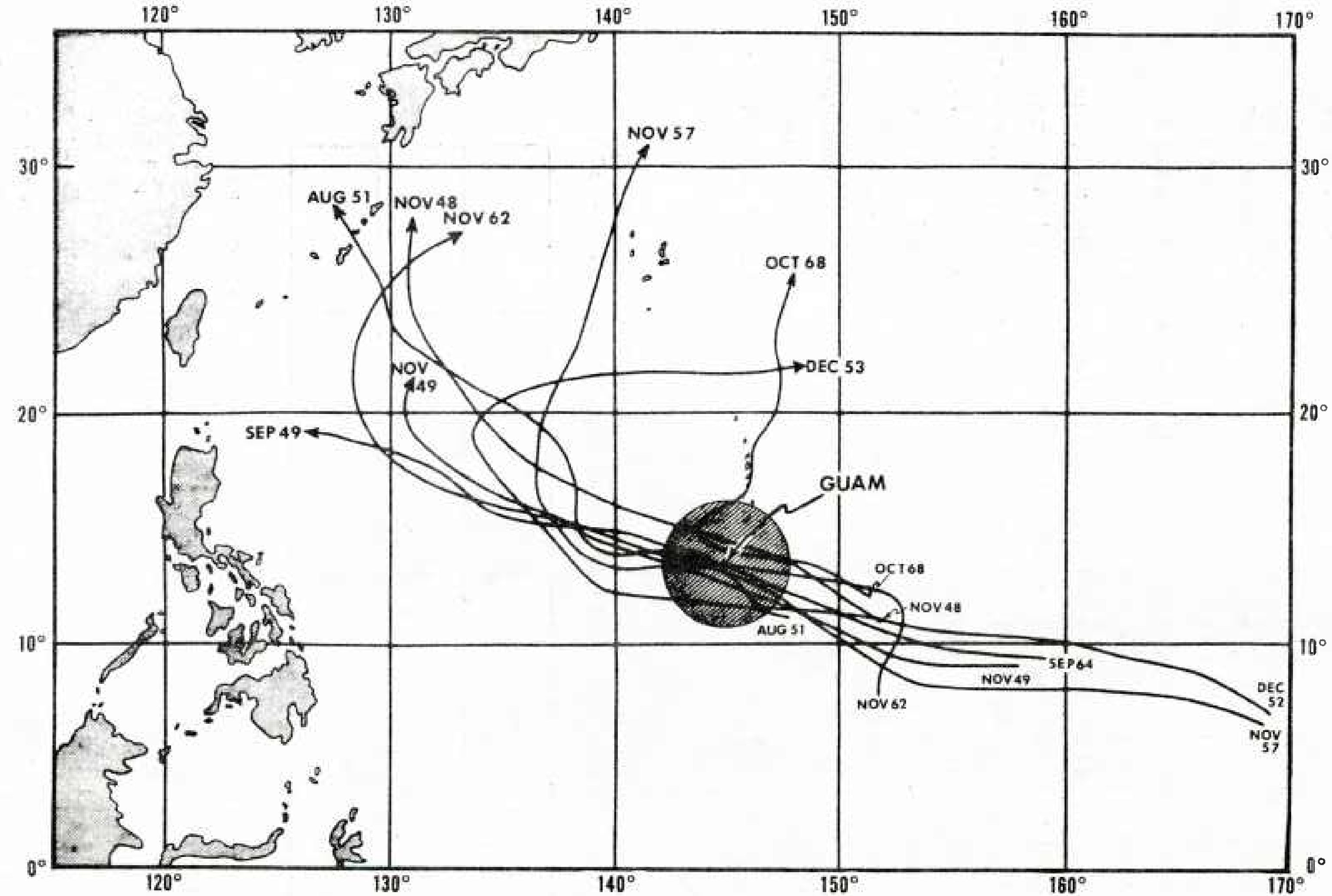

Figure 25. Tracks of the tropical cyclone that resulted in gale force winds ($\geq$ 34 kts) on Guam (based on hourly wind data recorded at NAS Agana from June-December, 1947-1973).

majority that caused gale force winds have approached along a major threat axis that is oriented east-southeast from Guam. This axis is also shown in Figures 18-24 by the "percent threat" lines and in Figure 5 by octant approach arrows.

Another significant feature indicated in Figure 25 is that of the eight storms that resulted in gale force winds during June-December 1947-1973, 4 occurred during the month of November. This is not to say that gale force winds may not occur during the other months (the fact is, WESTPAC typhoons can effect Guam during any month of the year) but climatology does indicate that the peak "threat" is apparent during November.

5.2 EFFECTS OF TOPOGRAPHY

Of the 107 tropical cylones that passed within 180 n mi of Guam in the June-December, 1947-1973 period, approximately 60% passed to the north and 40% passed to the south.

Figure 26 shows the positions of the tropical cyclone centers (June-December, 1947-1973) when strong winds ($\geq$22 kt) were first and last recorded at NAS Agana (based on hourly wind information). It is apparent that these strong winds do not occur until the storms reach approximately the longitude or just to the east of Guam. Notice that a number of storms will continue to give strong winds to Guam at distances of 200 n mi or more to the west. In general, strong winds can arise from storms passing 200 n mi to the south, and from storms passing 100 n mi to the north. There are more strong wind situations for storms passing to the south than to the north even though more storms had their CPA to the north. This is logical since storms passing south would place Guam in the high wind or dangerous semicircle. This bias is also evident in Figure 27, which shows the tropical cyclone center positions when gale force ($\geq$34 kt) winds were first and last

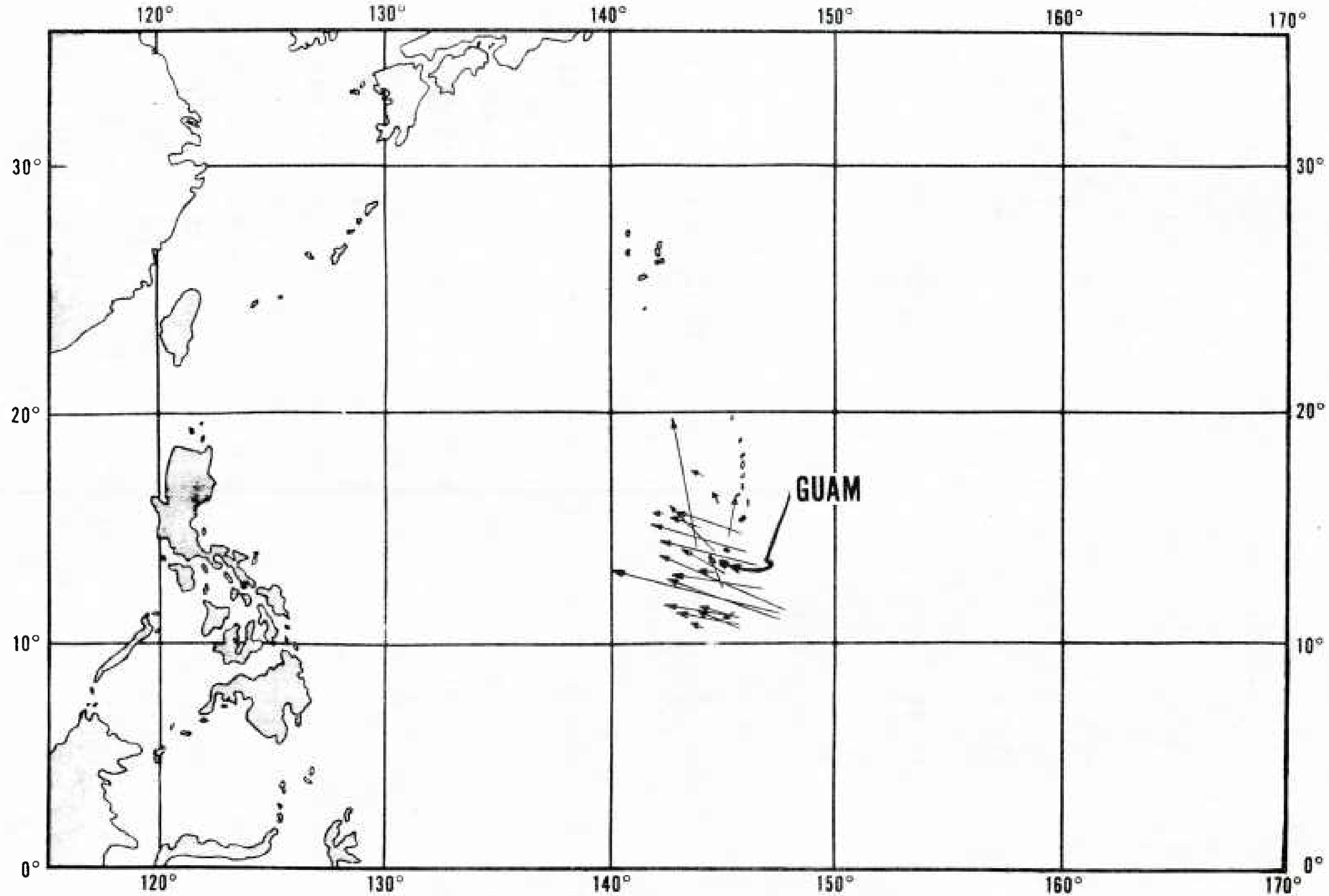

Figure 26. Positions of tropical cyclone centers when $\geq$ 22 kt winds first and last occurred at Guam. (Based on NAS Agana data from June-December, 1947-1973).

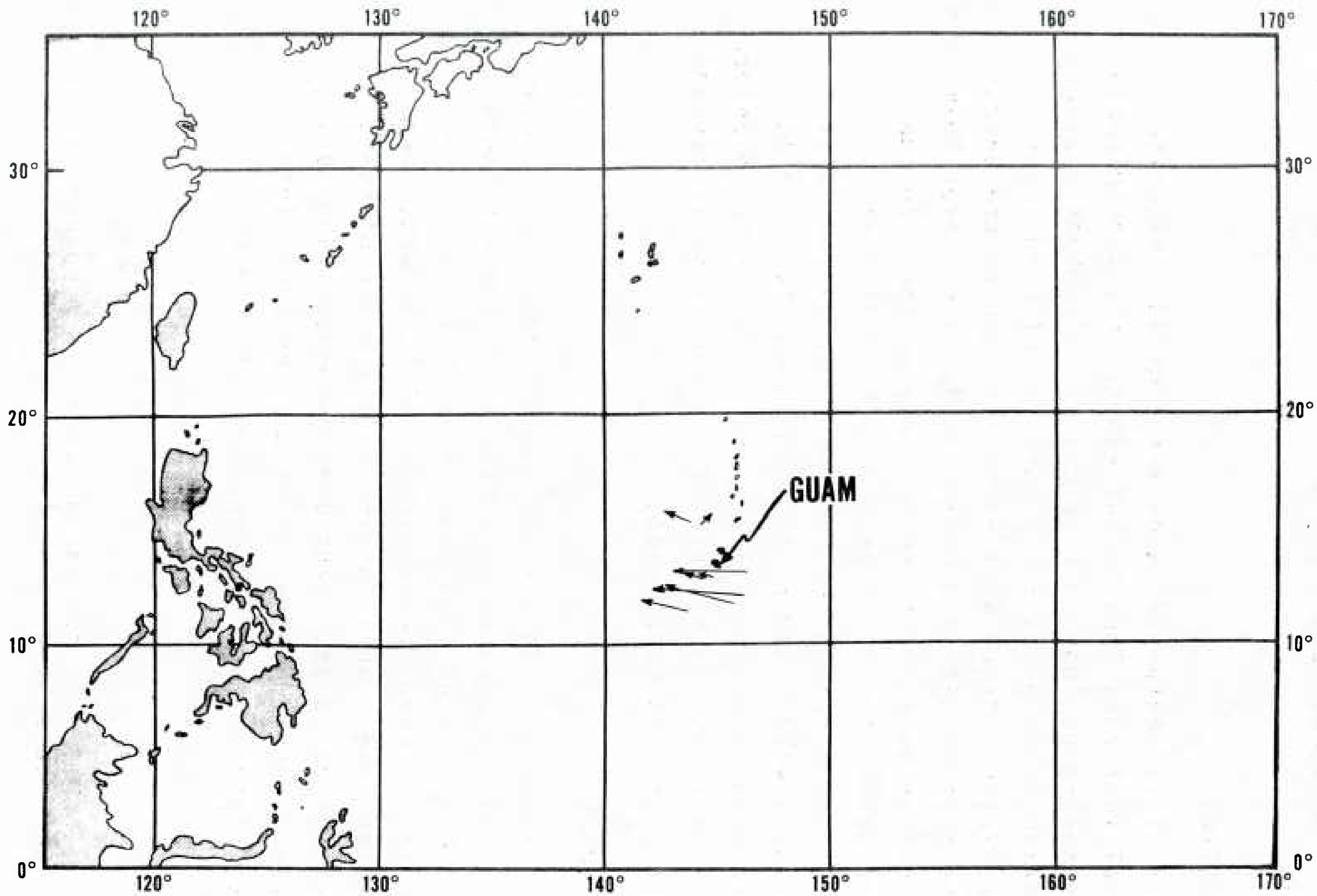

Figure 27. Positions of tropical cyclone centers when $\geq$ 34 kt winds first and last occurred at Guam. (Based on NAS Agana data from June-December, 1947-1973.)

recorded at NAS Agana. Notice that there was one gale occurrence at NAS Agana when the storm was centered over 200 n mi from Guam.

5.3 WAVE ACTION

Because of its extensive area and limited sheltering topographical features, Apra Harbor experiences considerable wave action during periods of tropical storm/typhoon passage.

Wave heights are primarily a function of wind speed, duration and fetch. Since Apra Harbor is open to the west, those storms that result in a westerly wind field over Guam expose the harbor entrance to severe wave action. In the outer harbor waves of 6-10 ft are "common" during storm passage and it is possible the maximum could exceed 20 ft under a westerly wind field of typhoon intensity.[5] It is important to keep in mind that wave action may commence before local wind conditions reach particularly dangerous levels and may continue after the winds abate.

5.4 STORM SURGE

Storm surge can be defined as the difference in observed water level at a given location during storm and non-storm conditions. Storm surge is a major problem in Apra Harbor. Typhoon conditions have created surges 10-12 ft above mean lower low water level, while at the northern tip of Guam, surges in excess of 18 feet have been recorded. Obviously, these extreme changes in water level must be taken into account when planning for heavy weather situations.

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[5]Details of wave action damage under typhoon conditions are contained in case studies of Appendix B.

6. PREPARATION FOR HEAVY WEATHER AT APRA HARBOR

6.1 TROPICAL CYCLONE WARNINGS

Western Pacific Ocean tropical cyclone warnings are issued by FWC/JTWC Guam. The warnings are numbered serially commencing with the first warning issued on each cyclone and continued throughout the life cycle of the cyclone irrespective of a change in classification. The initial warning will be issued when the existence of a tropical depression has been established and the decision to designate it has been made. In order to maximize the use of all available reconnaissance platforms and spread warning workload in multiple storm situations, a variable warning time may be employed. Warnings will be issued within 2 hours of 0000Z, 0600Z, 1200Z and 1800Z with the constraint that two consecutive warnings may not be more than 7 hours apart.

In addition to warnings, FWC/JTWC Guam issues a tropical cyclone formation alert when interpretation of synoptic and other meteorological data suggest that formation of a significant tropical cyclone is likely. Alerts are not numbered, but will specify a valid period not to exceed 24 hours and will either be cancelled or reissued by the end of the valid period.

Through aircraft reconnaissance and satellite observations, modern techniques for locating tropical cyclones and monitoring their progress have become quite sophisticated. Nevertheless, the present state of meteorological knowledge does not permit a perfect prediction of storm movements. As stated previously, many variables exist which can alter the path of a typhoon; hence, every typhoon should be treated with the utmost respect.

COMSEVENTHFLT OPORD 201-(YR), Annex H, describes the techniques to be used when plotting the FWC/JTWC typhoon warning track positions. The average 24-hr forecast error of 135 n mi should always be incorporated when plotting the 24-hr forecast position in order to expand the radius of 30-kt winds, given in the warning, by the average forecast error. Figure 28 demonstrates this procedure and utilizes the 135 n mi average 24-hr forecast position error in obtaining the "danger area." Note the radius of 30-kt winds is greater on the right side of the storm track -- the dangerous semicircle. In this example the radius to the 30-kt isotach is 200 n mi to the north and 150 n mi to the south of the storm at the current position. The radius to the 30-kt isotach is forecast to expand to 225 n mi to the north and 175 n mi to the south of the storm at the 24-hr forecast position. At the 24-hr forecast time the danger area is then 360 n mi (225 plus 135) to the north and 310 n mi (175 plus 135) to the south of the storm. The 48- and 72-hr forecasted positions given in the FWC/JTWC warning provide a planning forecast, but must also be adjusted to consider a 275 n mi and 400 n mi average forecast error, respectively.

The criteria for setting local weather readiness conditions are set forth in COMMANDER IN CHIEF PACIFIC REPRESENTATIVE GUAM AND THE TRUST TERRITORY OF THE PACIFIC ISLANDS and NAVAL FORCES MARIANAS JOINT INSTRUCTION 3141.1. In addition, this instruction requires specific action to be taken by various naval activities when weather conditions pose a threat to life or property. One such required action is that all Commanding Officers/Masters of Naval/Merchant ships present, attend a Heavy Weather Planning Meeting to discuss necessary action and the time required to complete this action. Since this meeting will cover evasion plans and heavy weather security it is imperative all personnel concerned attend.

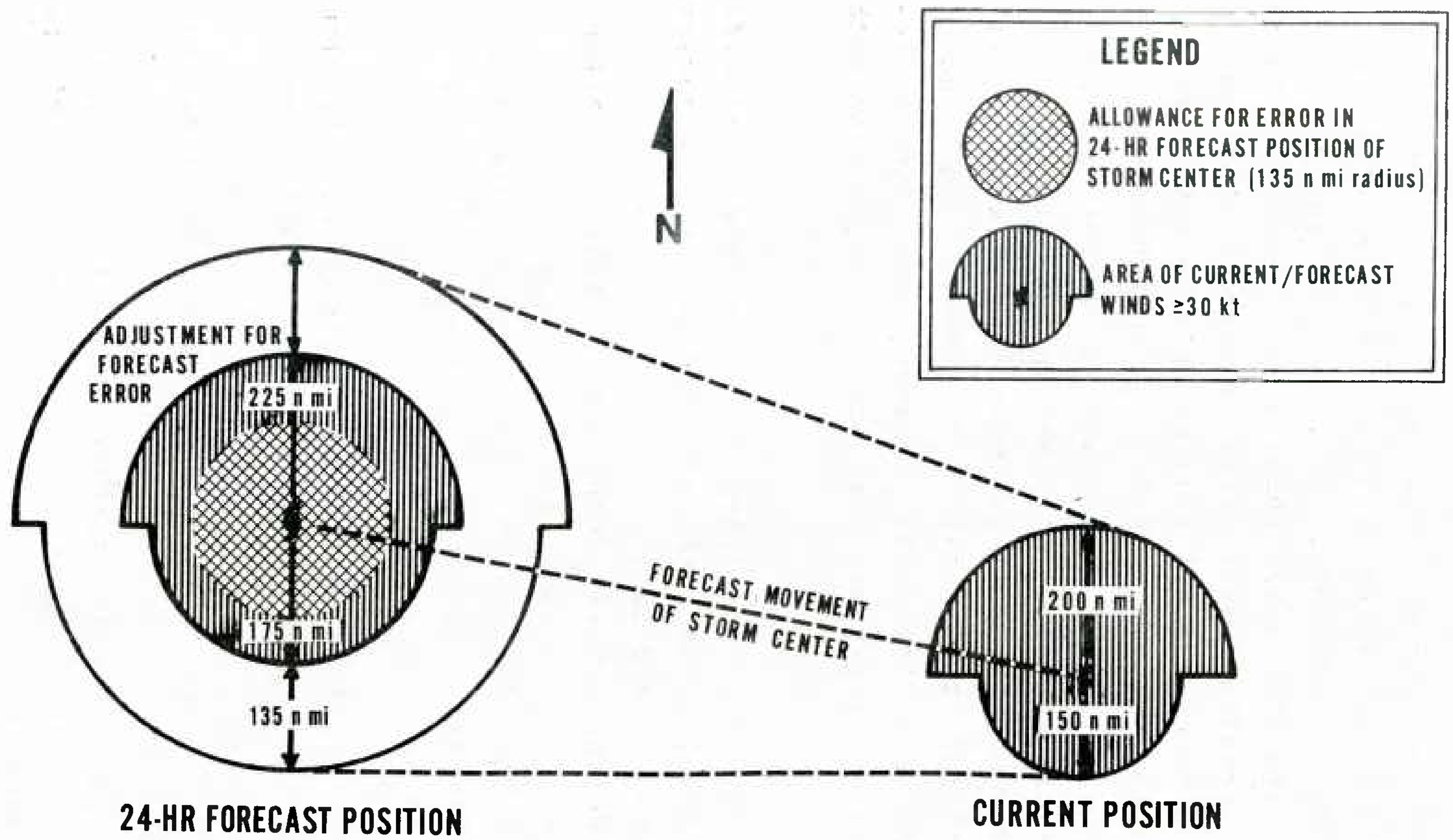

Figure 28. Method of calculating the danger area for moving typhoons and tropical storms (from Commander, Seventh Fleet, OPORD 201-YR).

6.2 EVASION RATIONALE

A most important aspect of any decision concerning heavy weather is an early appraisal of the threat posed by an individual tropical cyclone. Since the U.S. Navy's typhoon forecasting assets are readily available to units at Guam, a timely threat appraisal will be readily available and individual unit commanders will be able to take part in the evasion planning meetings called by COMNAVMARIANAS.

Historically, tropical cyclones have approached Guam from all directions and since most are in the developing stages, their movement as well as intensity and wind distribution, are difficult to forecast. This makes long range evasion planning very difficult. However, some rough guidelines that might be of use are presented in conjunction with Figure 29.

I. An existing tropical cyclone moves into or significant development takes place in area A with forecast movement toward Guam:
   a. Review material condition of ship. A sortie may be desirable 2-4 days hence.
   b. Reconsider any maintenance that would render the ship incapable of getting underway within 48 hours.

II. Tropical cyclone moves into or significant development takes place in area B with forecast movement toward Guam:
   a. All units consider possible course of action if sortie should be ordered.
   b. Reconsider any maintenance that would render the ship incapable of getting underway within 24 hours.

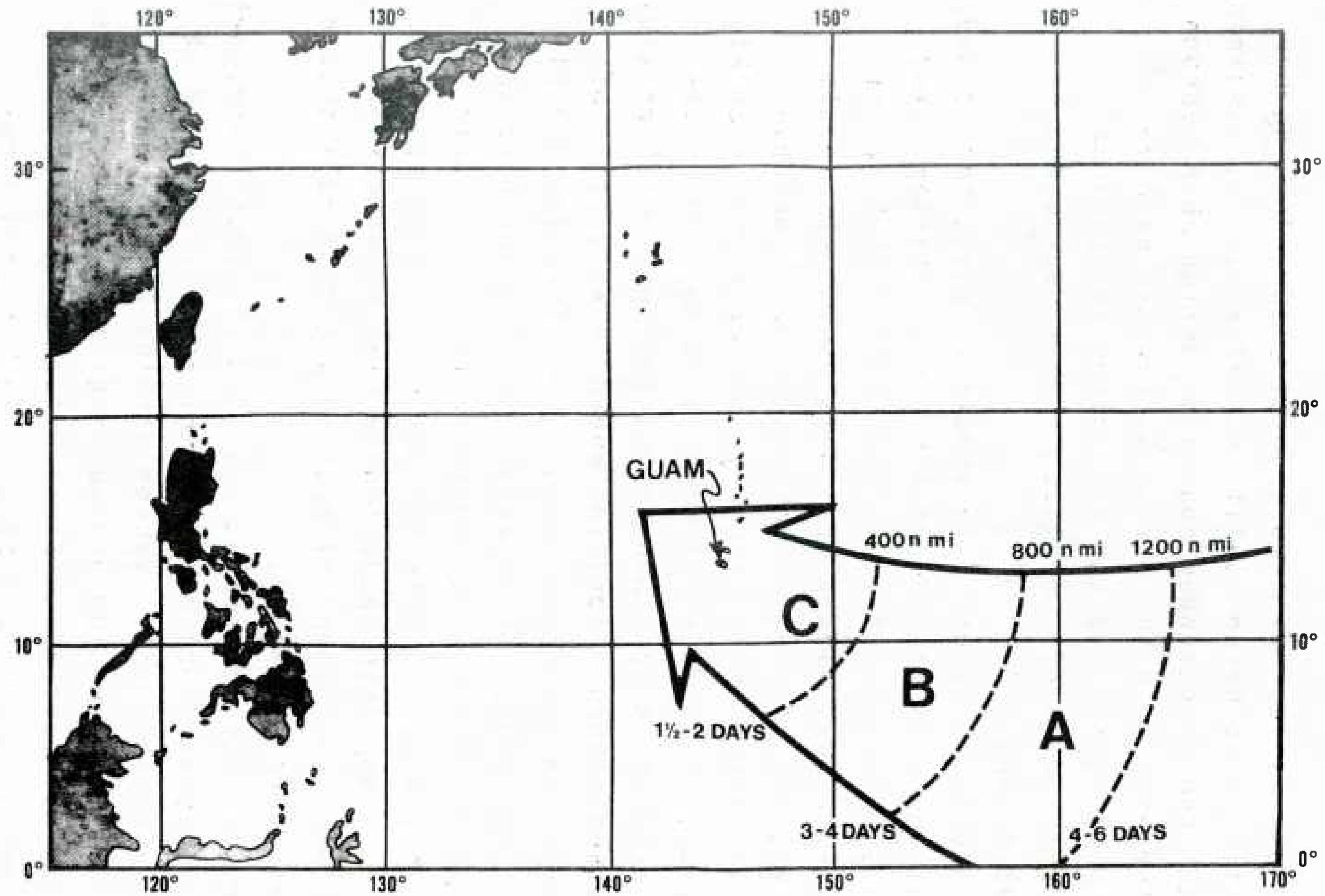

Figure 29. Tropical cyclone threat axis for Guam. Distances and approach times are measured from Guam based on an 8-12 kt speed of movement.

III. Tropical cyclone enters area C moving toward Guam:

a. Execute sortie.

6.3 REMAINING IN PORT

Because of its lack of natural protection, Apra Harbor provides little or no haven qualities. As a result, remaining in port is not the recommended course of action when typhoon conditions threaten. In the past U.S. Navy ships have remained in port during typhoon conditions for various reasons. Case studies of two situations are presented in this study as Appendix B.

Should a unit be required to remain in port, berths and/or nesting assignments will be made by Naval Station Guam/SOPA (ADMIN) Guam as specified in COMNAVMARIANAS Disaster Preparedness Plan 101. Individual unit commanders should be ready to rapidly respond to movement orders, because maneuvering after the onset of heavy weather (winds $\geq$ 20 kt) will be extremely hazardous. Remaining in port poses the problem of deciding on and then requesting the "best" possible mooring location. Such a location would be a function of ship type, expected sea state, wind speed/direction and time available for the move. In Appendix B it is concluded that a general rule for winds up to 50 kt would be: "Obtain an inner harbor berth as close to the upwind shore as possible." It is recognized any ship subjected to high winds while moored will take some amount of beating but this rule should minimize the damage sustained.

Weather warnings concerning Guam and the trust territories of the Pacific islands are based on information gathered at Fleet Weather Central/Joint Typhoon Warning Center, Guam (FWC/JTWC). All information and warnings are then broadcast to fleet units on appropriate Fleet Broadcast Channels. In addition, warnings are broadcast on Apra Harbor Control

Frequency 2716 KHZ and Tug Control Frequency 3216 KHZ during typhoon/tropical storm conditions.

6.4 EVASION AT SEA

Evasion at sea is the preferred course of action when confronted with potential typhoon conditions on Guam. The commanding officer, with his experience and knowledge of his unit, will always make the final evasion decisions; however, the following evasion techniques are suggested for the more common "threat" situations.

I. Tropical cyclone approaching from the east or southeast and forecast to pass north or within 60 n mi south of Guam.
   a. Evasion should be southwest. The units will be in the safe or navigable semicircle with following wind and sea.

II. Tropical cyclone approaching from the east or southeast and forecast to pass more than 60 n mi south of Guam:
   a. Evasion should be northeast.

III. Tropical cyclone approaching from the south and forecast to pass east of Guam:
   a. Evasion should be west-southwest.

IV. Tropical cyclone approaching from the south and forecast to pass west of Guam:
   a. Evasion should be east-southeast.

In evading, whichever case presents itself, the following general comments should be noted:

1. Crossing ahead of an approaching typhoon as recommended in I above, is not without hazard, and must be accomplished well ahead of the typhoon. If, in attempting this track crossing, the ship is caught in the wave/swell pattern ahead of the storm, the speed of advance may be reduced to the point that the ship will be unable to maneuver clear of the storm (see Appendix D).

2. It is very possible during the peak typhoon season for rapid storm development to occur, resulting in multiple tropical cyclones co-existing in the western Pacific area. (This occurs approximately 50 days of each year.) This possibility would greatly complicate the evasion problem, and should be kept in mind as evasion plans are formulated and executed.

7. CONCLUSION

There are no aspects of Apra Harbor that recommend it as a typhoon haven. The surrounding topography is low and does not provide an extensive wind break. The harbor entrance is open to the west and is in close proximity to the berths and moorings in the outer harbor. Consequently, westerly winds and seas associated with the typhoon passage have a devastating effect within the harbor.

In the past all U.S. Navy ships capable have sortied from the harbor upon the approach of a typhoon. Additionally, the Port Operations Officer desires that ships not use Apra Harbor as a typhoon haven since the harbor's and NAVSHIPREPFAC Guam's yard and service craft occupy virtually all desirable berths in the harbor during typhoon conditions.

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APPENDIX A

Figures A-1 through A-11 show monthly and half-monthly (June-Dec) tracks of western North Pacific (1946-1969) tropical cyclones which were at one time of typhoon intensity (Gray, 1970).

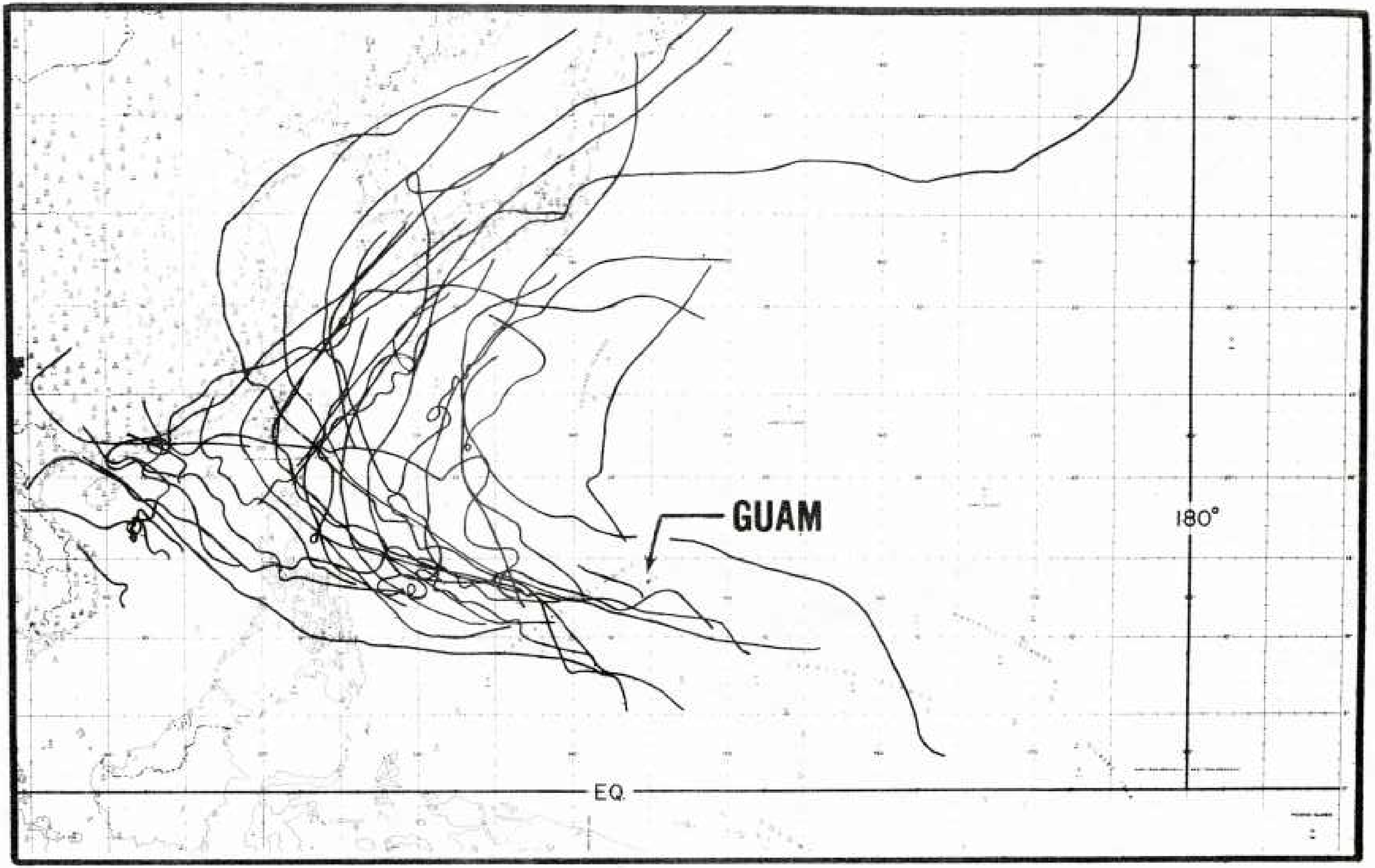


Figure A-1. June tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

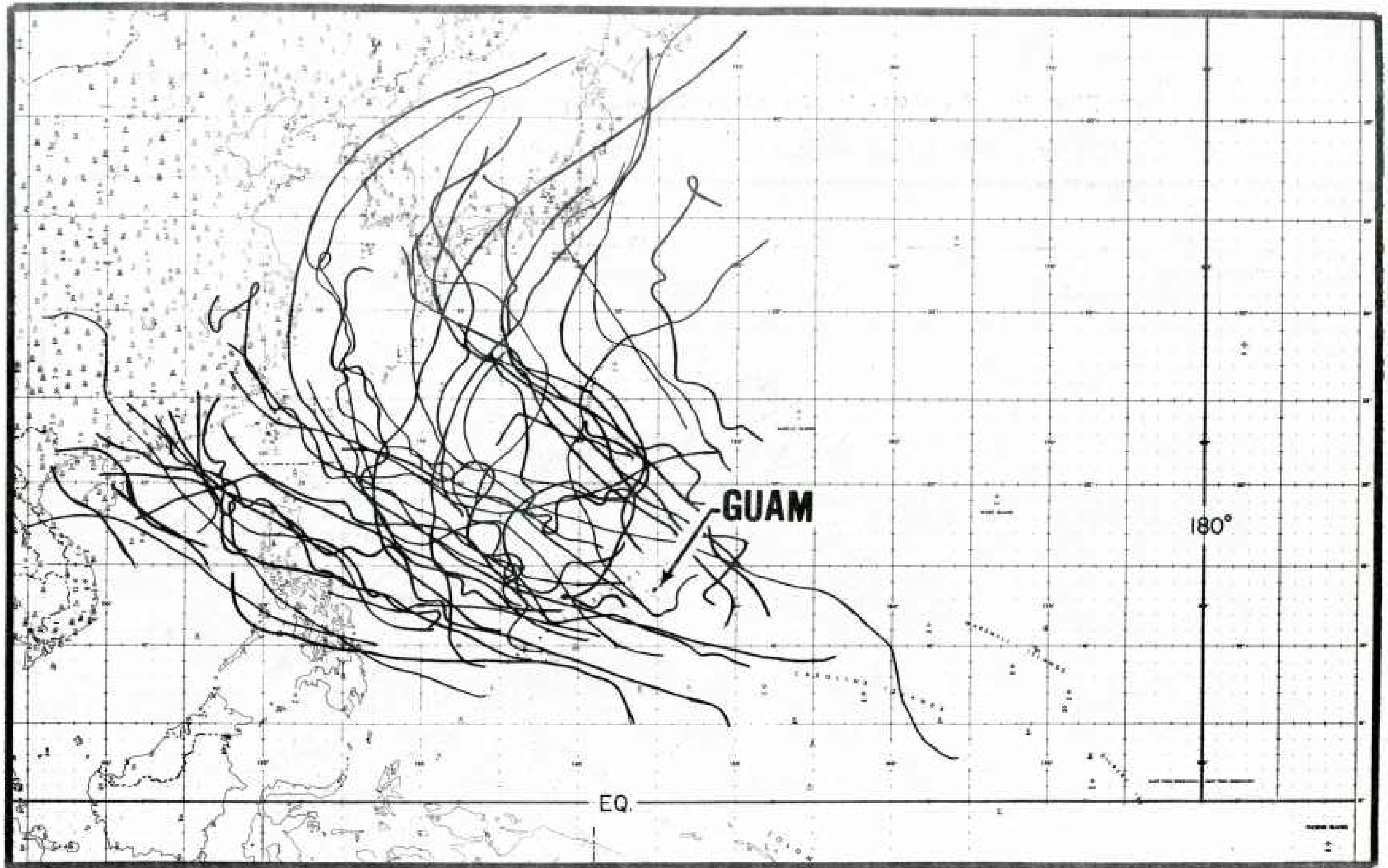


Figure A-2. July (first half) tracks of tropical cyclones which at some time were typhoons furing the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

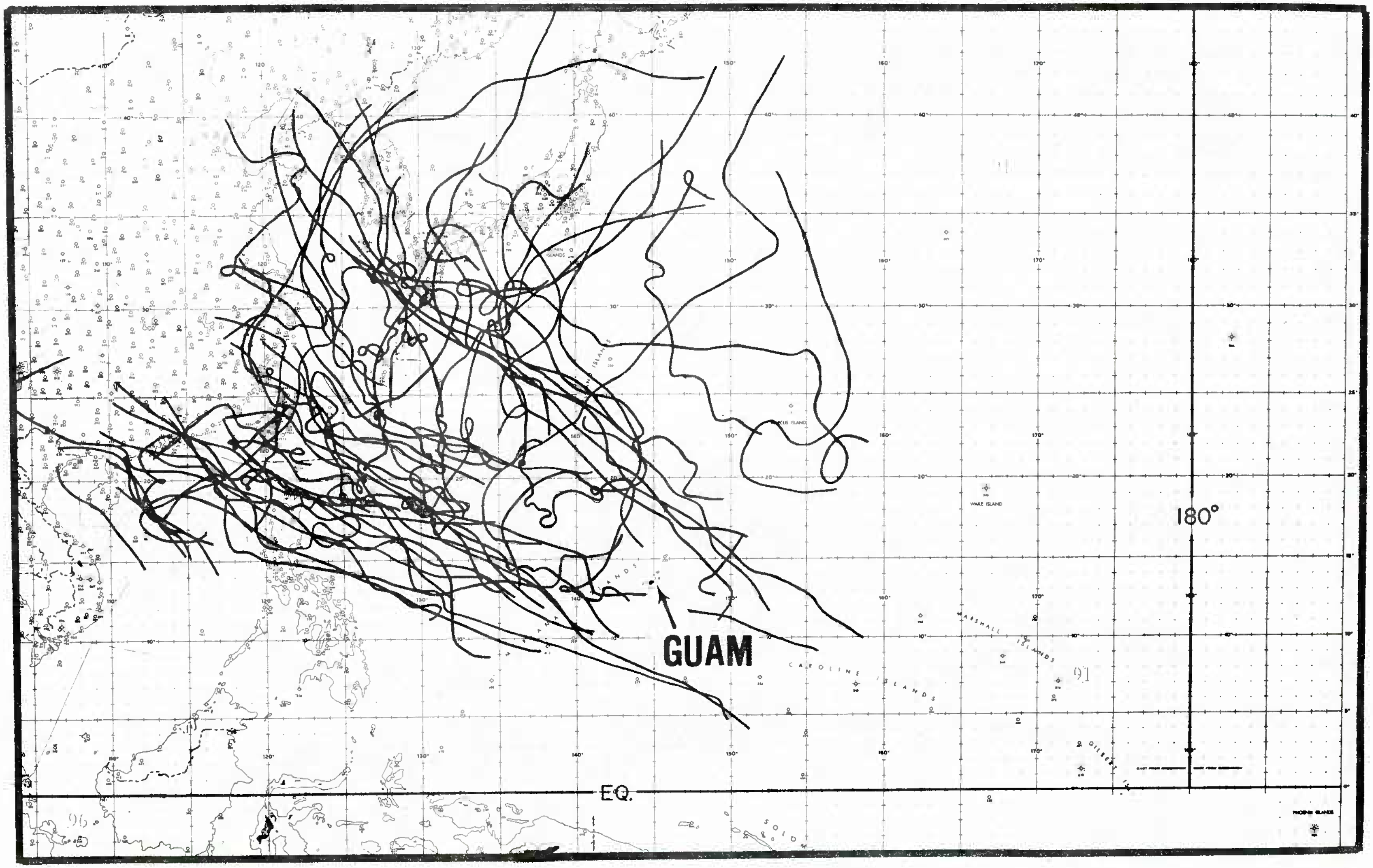


Figure A-3. July (second half) tracks of tropical cyclone which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

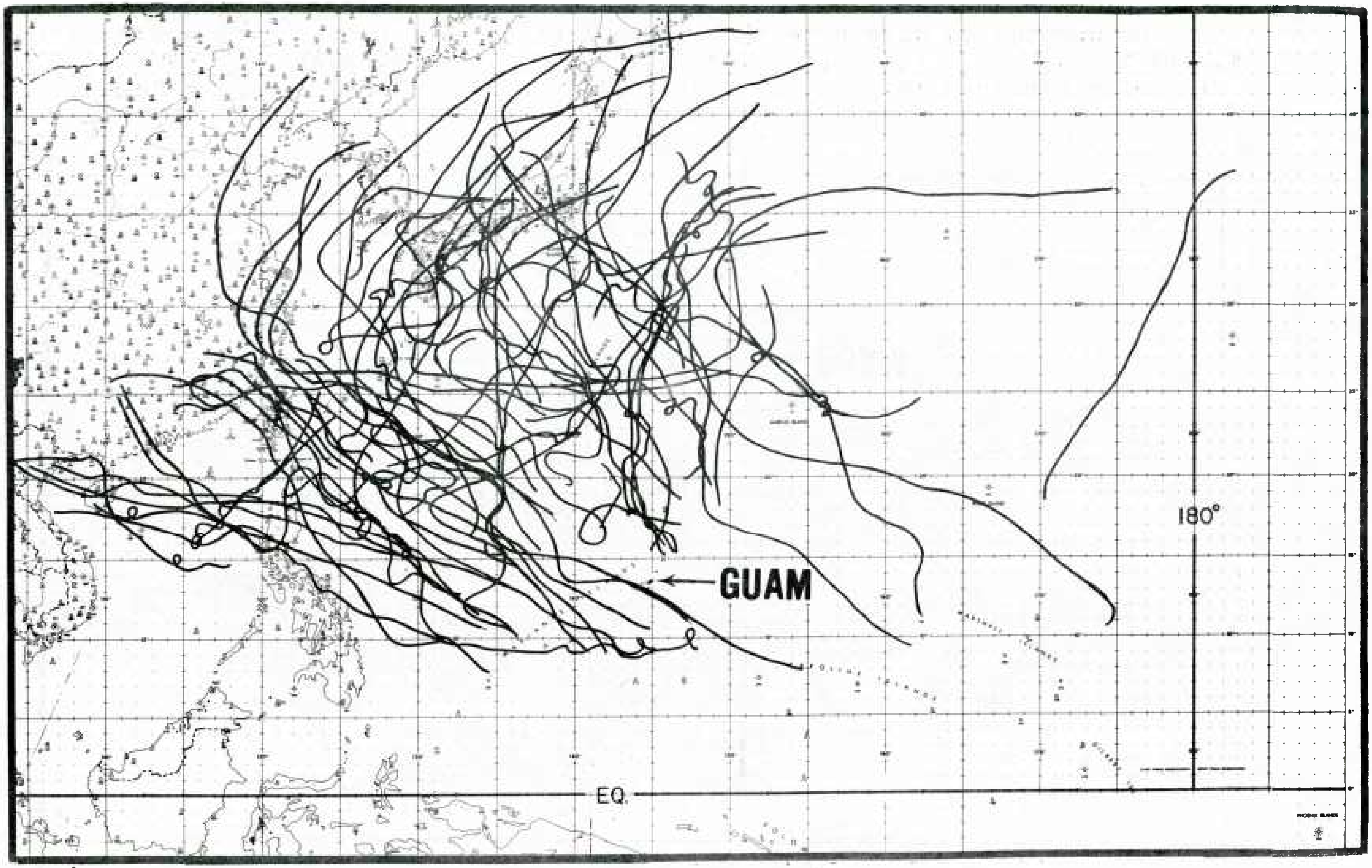


Figure A-4. August (first half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

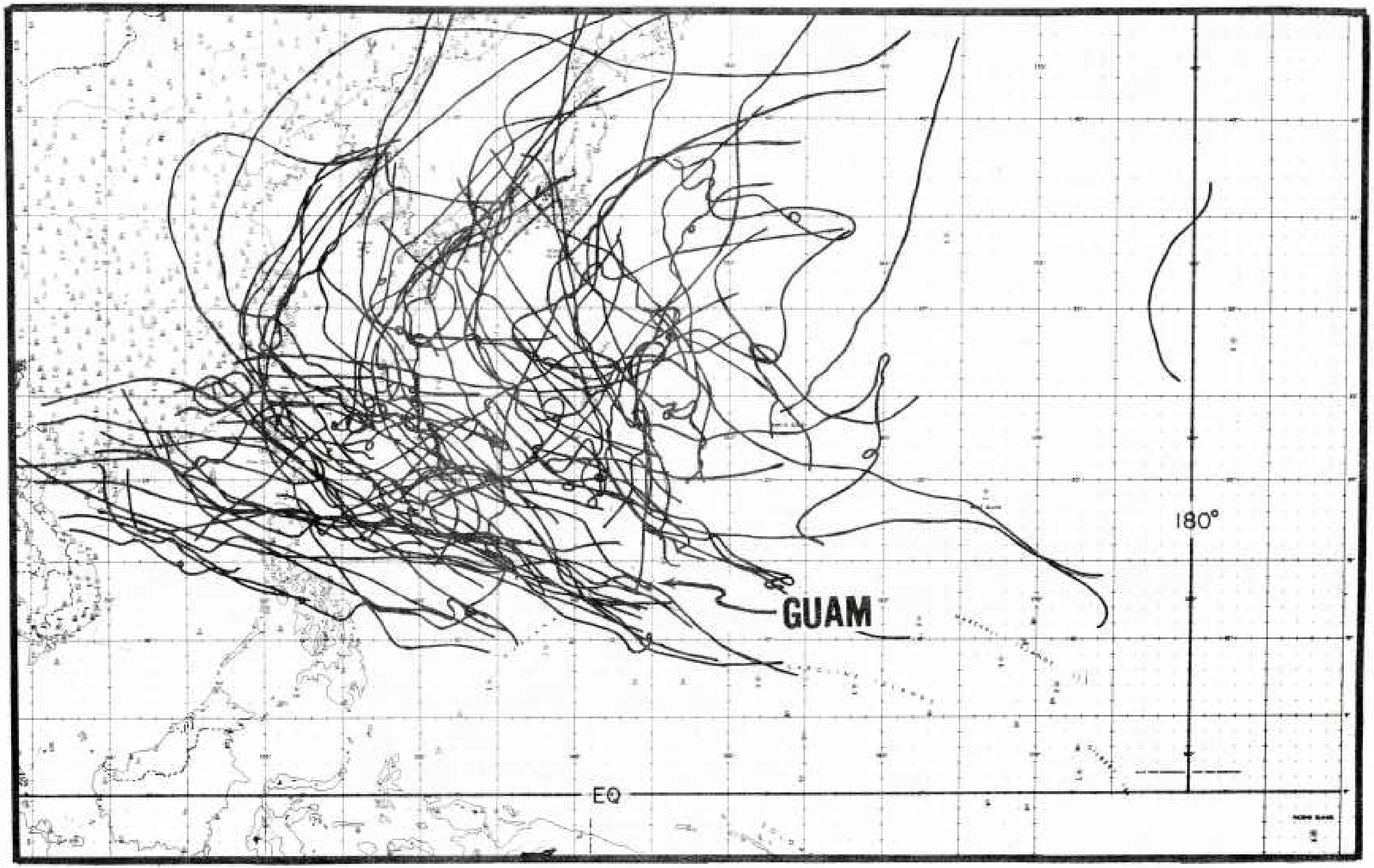


Figure A-5. August (second half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

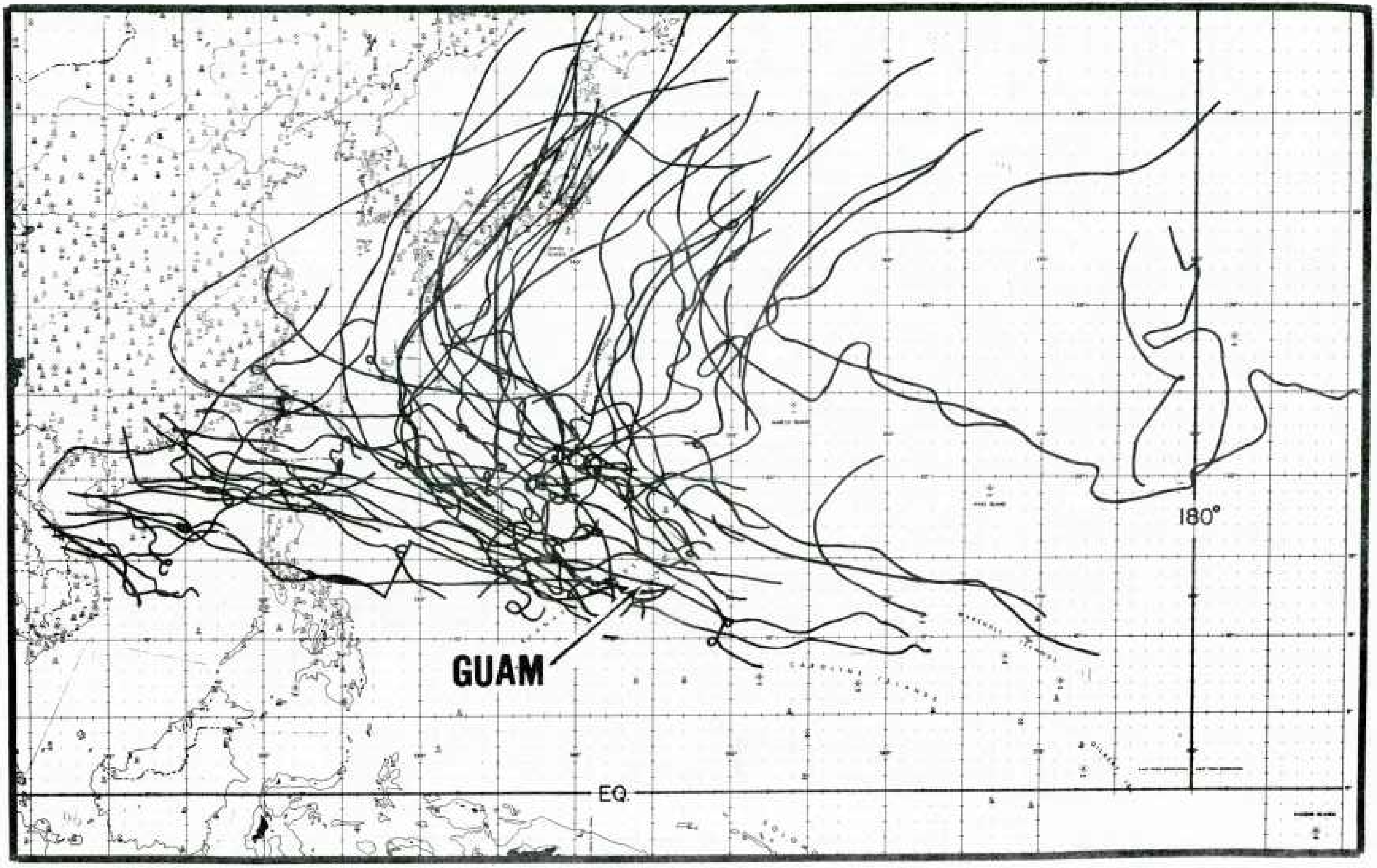


Figure A-6. September (first half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

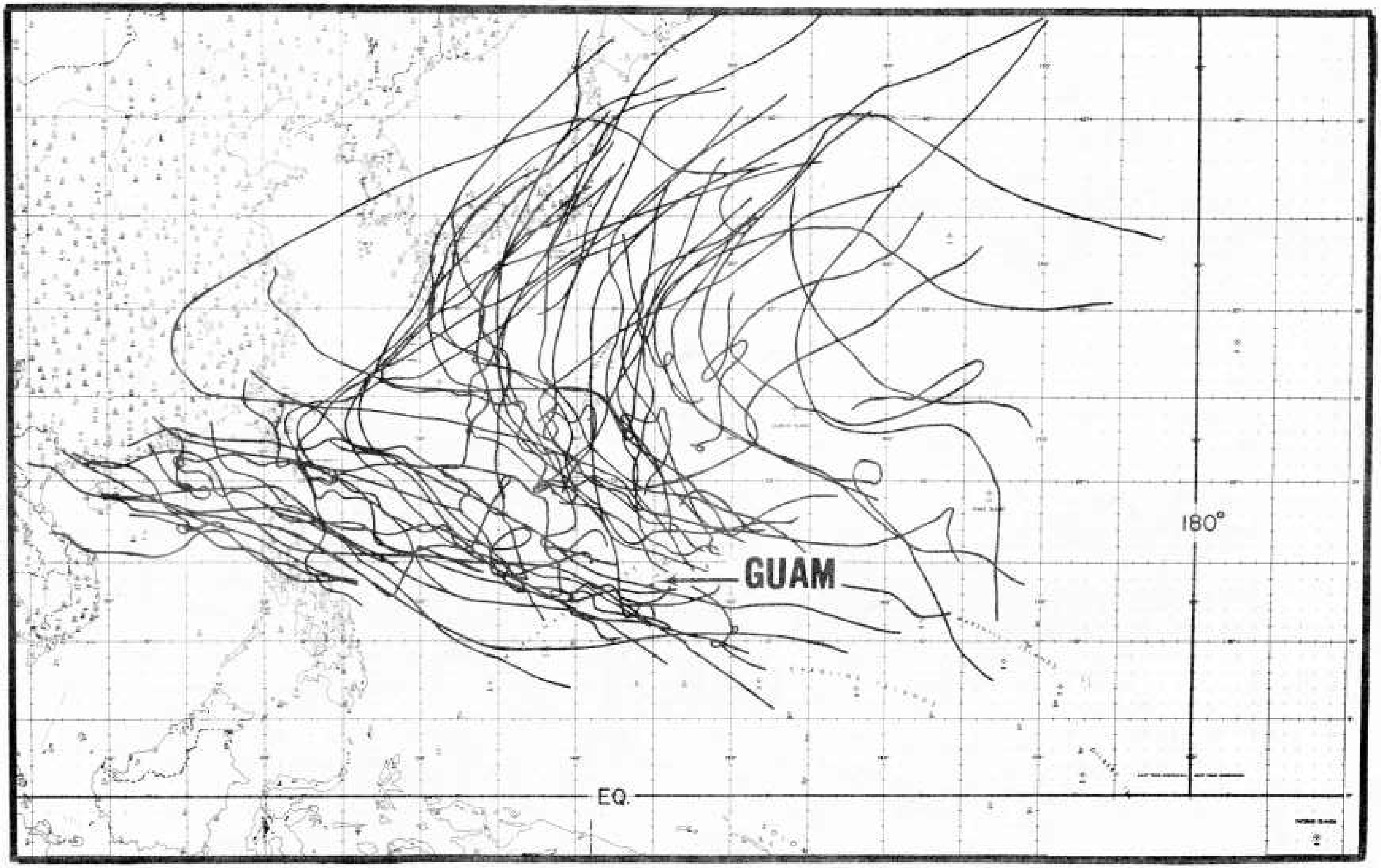


Figure A-7. September (second half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

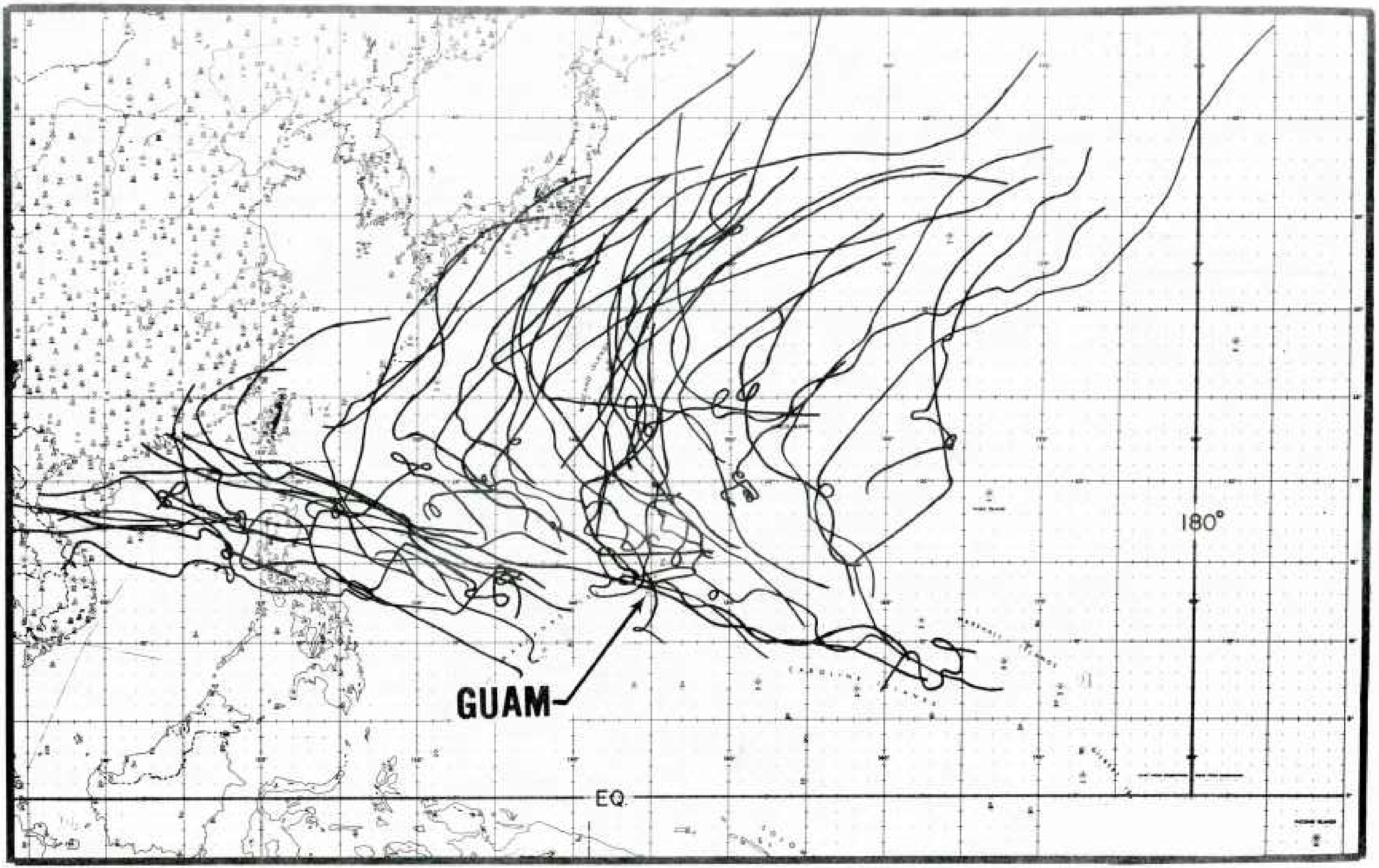


Figure A-8. October (first half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

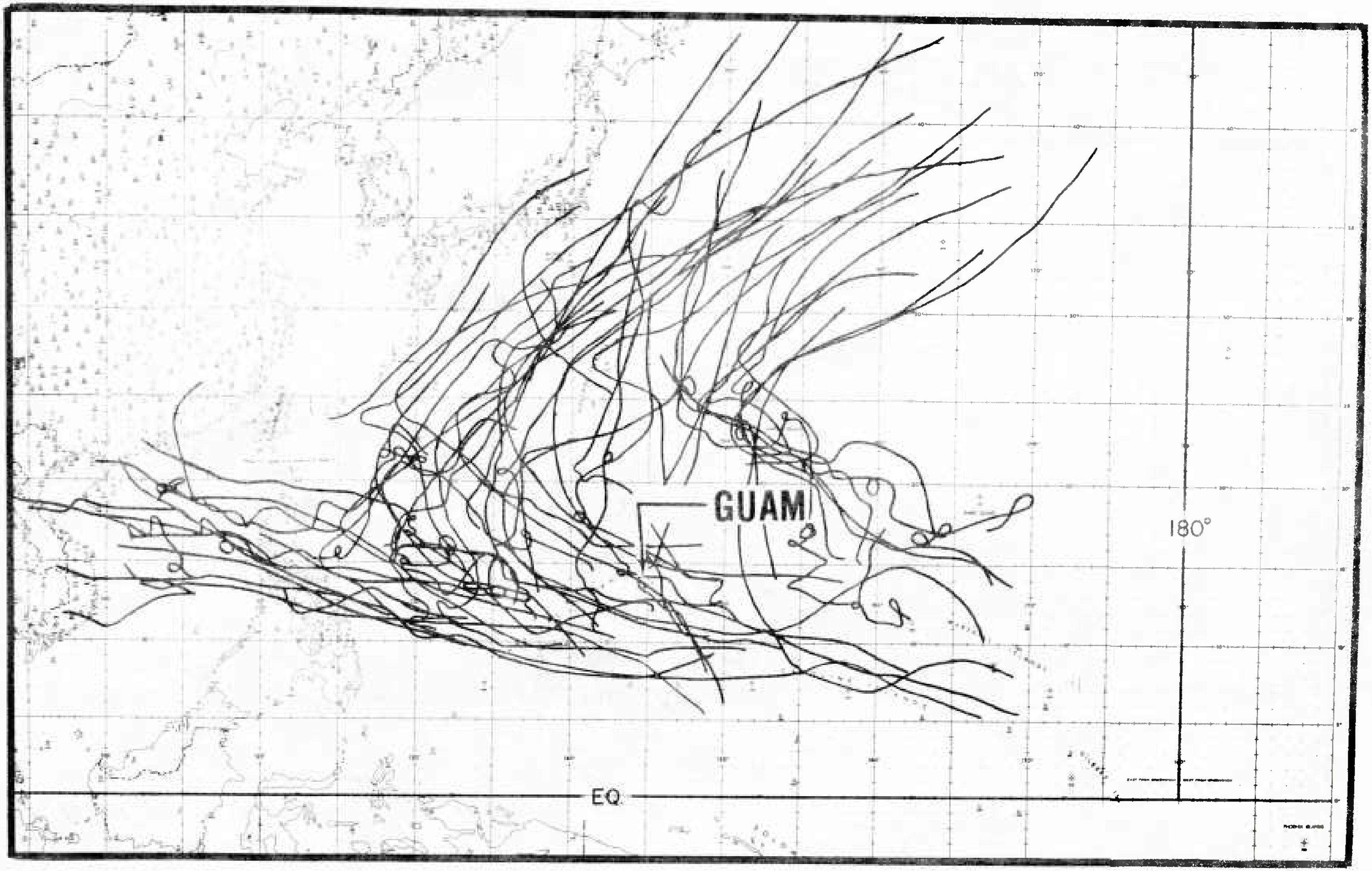


Figure A-9. October (second half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

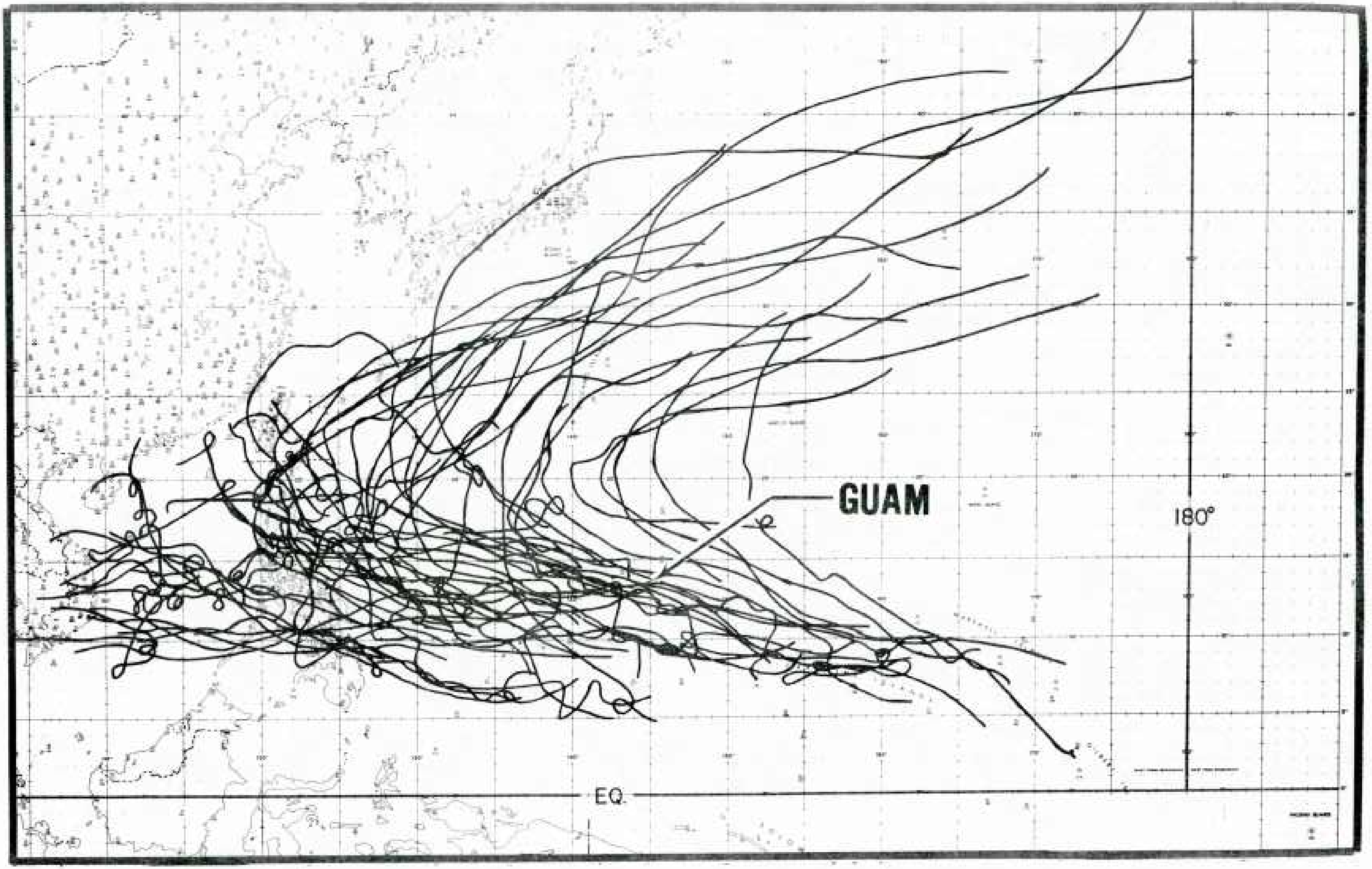


Figure A-10. November tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

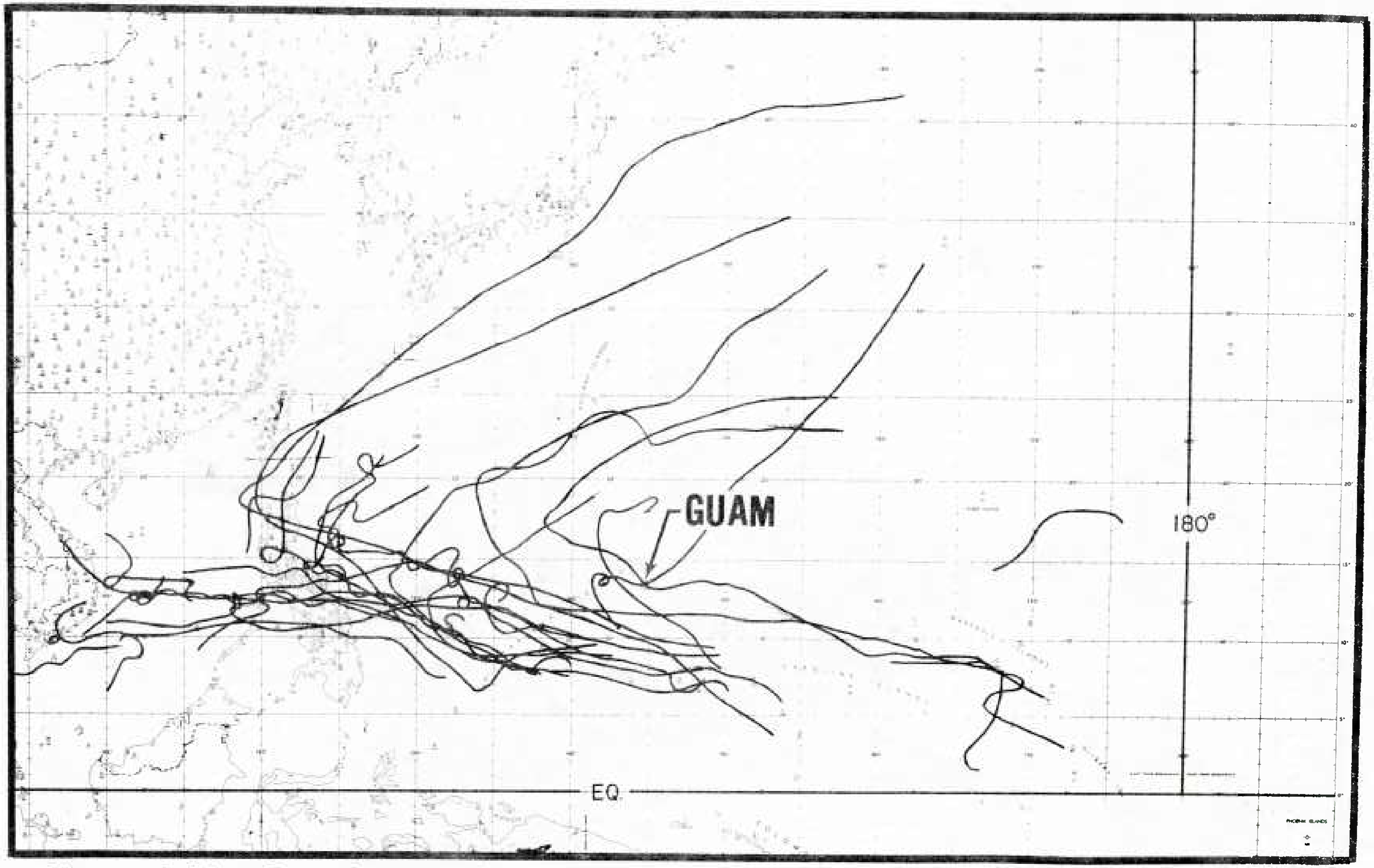


Figure A-11. December tracks of tropical cyclones which at some time were typhoons during the years 1946-1969. Tropical cyclones have been placed into monthly categories according to the median date of their existence.

APPENDIX B

Case studies of Typhoon Karen (11 Nov 1962) and Typhoon Olive (29 April 1963).

ABSTRACT

The cases of Typhoons Karen and Olive, described briefly in this section are evidence of Apra Harbor's inability to provide appreciable protection against typhoon damage.

TYPHOON KAREN (NOV 1962)
(Based on FWC Guam Special Typhoon Report of 23 Nov 1962)

The Island of Guam had approximately four days warning to prepare for Typhoon Karen which struck on 11 November 1962 (see Best Track chart Figure B-1). The center of Karen's eye passed across the southern part of Guam, four n mi north of the southern tip of the island and nine n mi south of FWC/JTWC, located on Nimitz Hill, moving 265 degrees with a speed of 17 kt. The diameter of the eye in relation to the wall clouds was eight n mi, while the diameter of the wind eye was approximately six n mi.

During the passage of this storm, Apra Harbor was hit by sustained winds of 150 kt and gusts up to 180 kt. The winds raised tumultuous seas in the inner and outer harbors, notwithstanding the short fetch, and caused all ships and craft to beat heavily against their piers and moorings. Precautionary measures for the typhoon were in accordance with current instructions. All ships capable of steaming sortied from the harbor prior to the typhoon's arrival. Other precautions were:

(a) All small craft including LCM's were lifted from the water and placed on Wharf "L".

(b) All non self-propelled active craft, too large to be removed from the water, were moored to buoys in the Inner Harbor.

(c) YD-120, a 125 long ton capacity floating crane, was secured at the pier on Wharf "U" using a well-tested typhoon mooring plan.

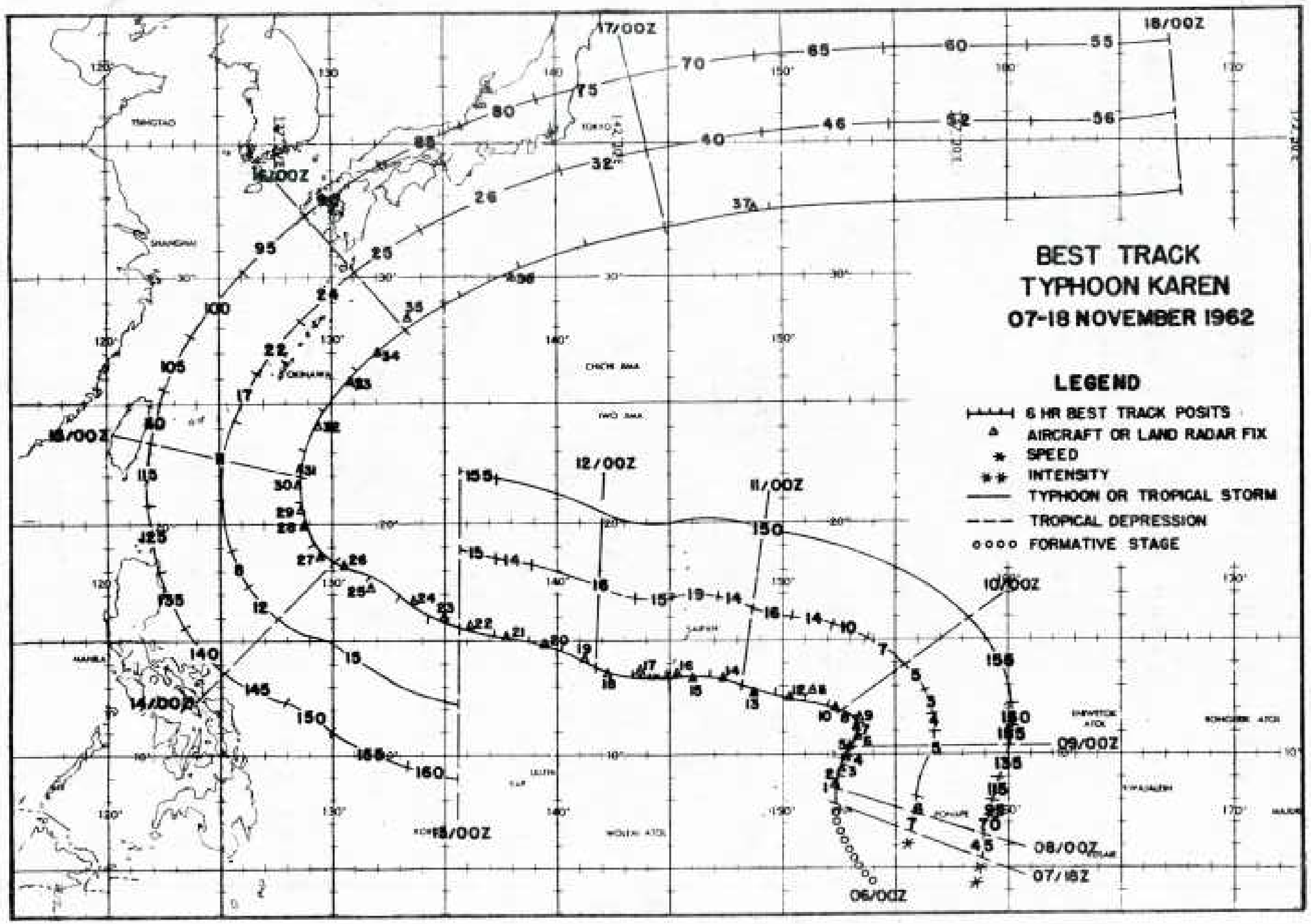


Figure B-1. Best track of Typhoon Karen (7-18 November, 1962).

(d) Two YOG's and four YTM's were secured to their berths on Wharf "V" at the tug base. One YTM was moored at a buoy in the Inner Harbor.

(e) Out of Service - In Reserve Craft always moored at Drydock Point with typhoon secure moorings received no special precautions.

(f) Two PC's, being modernized at SRF, had access openings replaced in a temporary fashion and their moorings at Wharfs "N" and "O" were greatly strengthened.

The harbor was hit with 150 kt sustained winds and 180 kt gusts during the passage of Karen. The following damage was inflicted (see Figure B-2):

(1) ROKS Han Ra San (PC-705), an Ex-USN 173 foot PC, capsized and sank at its berth at Wharf "O".

(2) RPS Negros Oriental (C-26), the same type ship as PC-705, capsized and sank at its berth at the west end of Wharf "N".

(3) The Trust Territory 10 inch hydraulic dredge JOHN S. CAMPBELL sunk adjacent to the east end of Wharf "N".

(4) The YFN - 693 broke loose from its typhoon mooring at a buoy in the Inner Harbor and floated free. It was seen the morning of the 12th of November passing Drydock Point on a northerly course and was noted to have a large hole in the corner of the hull. The YFN - 693 went aground and sank 300 yards west of Berth "F".

(5) YC - 1419 also broke loose from its mooring at a buoy in the Inner Harbor and went aground on the north side of Pad Five.

(6) YSR - 11 broke its mooring at Drydock Point and was found floating in a cove immediately west of Berth "H".

(7) YSR - 19 broke its mooring at Drydock Point and grounded on the Glass Breakwater about 1,500 yards from the harbor entrance.

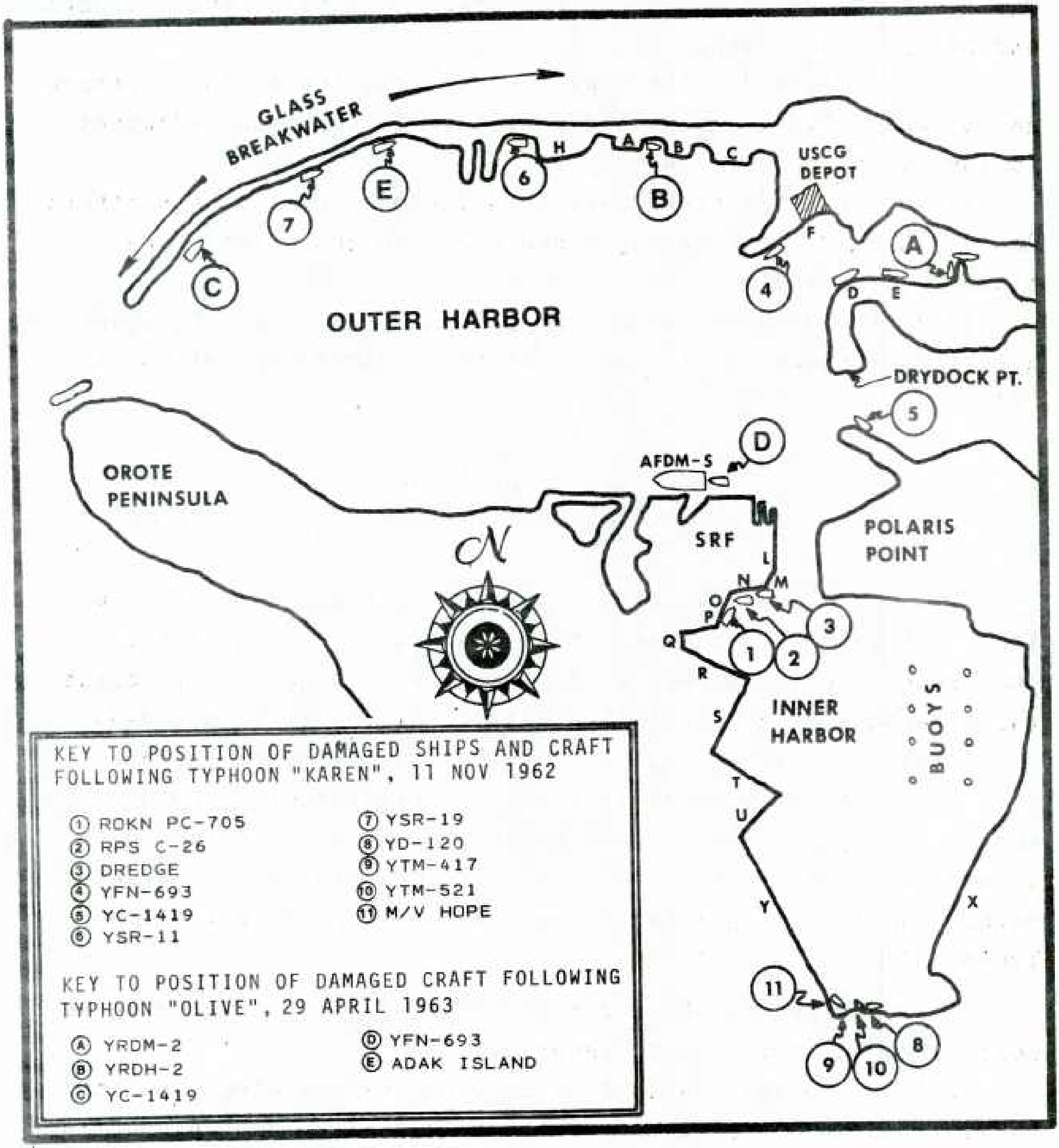


Figure B-2. Apra Harbor, Guam showing the locations of damaged ships and craft following Typhoons Karen and Olive.

(8) YD - 120 broke its mooring at the northern end of Wharf "U" and grounded on the LST beaching ramp at the southern end of the Inner Harbor.

(9) YTM - 417 broke away from its mooring at the northern end of Wharf "V" and broached port side to the beach adjacent to the southern end of Wharf "V".

(10) YTM - 521 broke away from its mooring at the northern end of Wharf "V" and grounded bow first on the beach immediately east of YTM - 417.

(11) The MV Hope, an ex YMS 200-ton wooden vessel, sank after heavy damage at its berth at the southern end of Wharf "V".

TYPHOON OLIVE (April 1963)
(Based on FWC Guam Special Typhoon Report of 7 May 1963)

Typhoon Olive gave little warning to the Island of Guam. The first warning was given at 1015 Sunday, 28 April 1963. The eye of the storm passed 20 n mi west on a northerly course the afternoon of 29 April (see Best Track chart, Figure B-3)

Typhoon Olive generated waves of 30 to 40 feet in the open sea. The mean waves inside the barrier reef of Guam were 6 to 10 feet, while Apra Harbor had waves of 6 feet with a mean high water mark of 3 to 4 feet above the mean low water mark. The following measures were taken in preparation for Typhoon Olive:

(1) Two PCs at SRF under the Military Assistance Program were taken to buoys in the Inner Harbor.

(2) All other craft which were not secure were taken to buoys if possible. Because of the late start, the rapid build up of the winds, and since the Naval Station had only three operable tugs, this could not be completely carried out. It became too rough in the Outer Harbor by early evening and too windy to move the larger craft such as the YD - 120 and an APL.

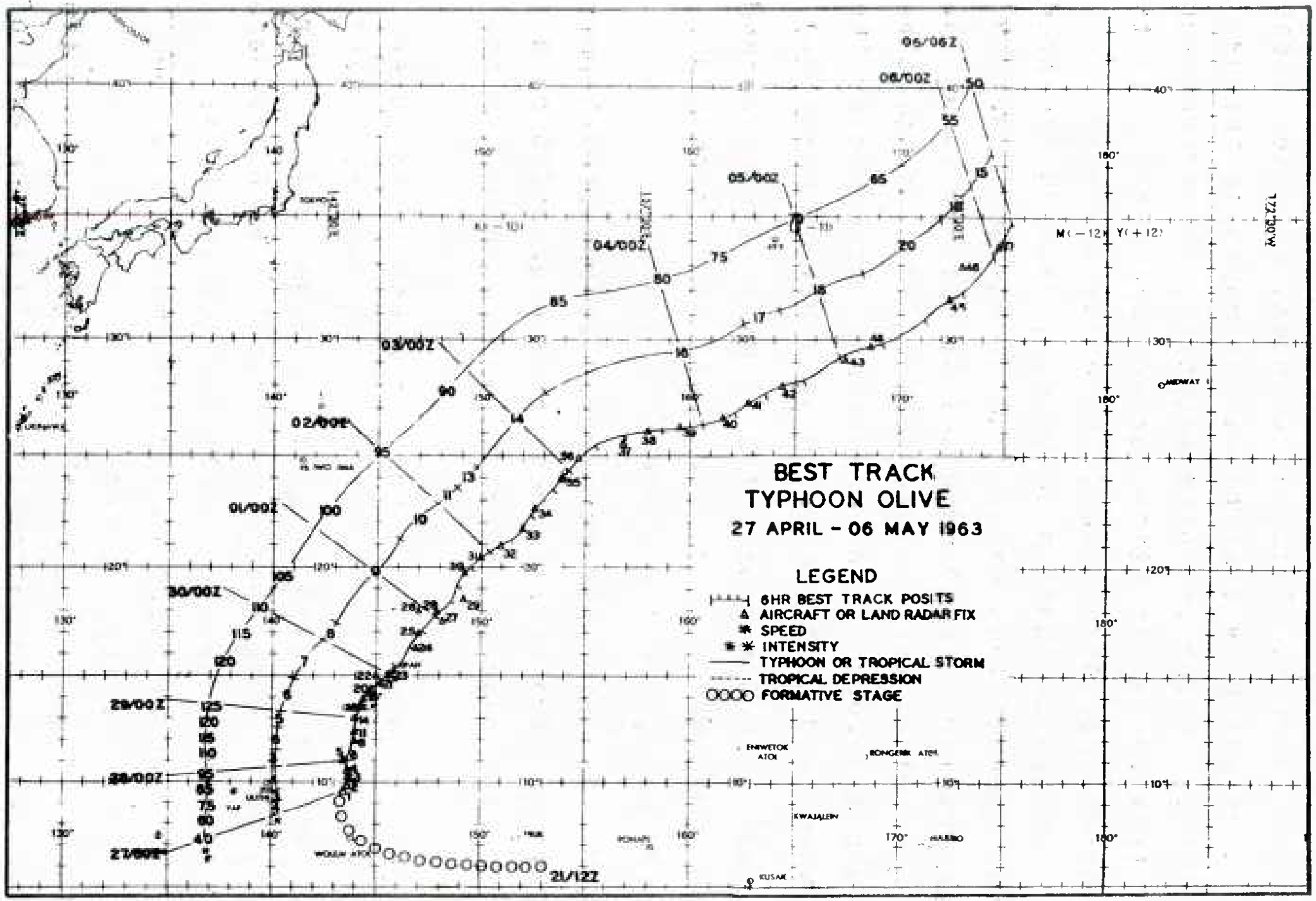


Figure B-3. Best track of Typhoon Olive (27 April-6 May, 1963).

(3) The Trust Territory dredge John S. Campbell had just been rebuilt following Karen damage and a secure haven for the dredge was sought. It was finally decided to beach the dredge broadside to the LST beaching ramp at the south end of Inner Apra Harbor. This position was selected because it appeared to be unlikely that the winds would be northerly during the storm. In the proposed location, the dredge would be protected from three directions other than north. If the storm did generate northern winds, the waves may have destroyed or damaged the wooden deckhouse, causing the dredge to swamp. But even in that event, the dredge would not be a major salvage problem. The dredge was beached at about 2300 on 28 April, and wires were passed to bollards and stretched taught by two bulldozers. (The dredge was undamaged by the storm and was removed from the beach on 3 May by one YTM.)

Maximum winds in Olive were 125 kt while winds reached 88 kt at Guam. Damage to ships and craft which required salvage efforts was as follows (see Figure B-2):

(a) YRDM - 2, which had been moved to an outer harbor buoy, broke its 2" wire mooring pendant and grounded on a spit of land to the east of Wharf "F" and south of Cabras Island.

(b) YRDH - 2, which had also been moved to an outer harbor buoy, parted its mooring bridle (two legs of 1 5/8" wire) and was driven aground on a coral ledge west of Pier "B".

(c) YC - 1419, which had been moored to an Outer Harbor buoy, broke loose and damaged itself against the Glass Breakwater. It sank adjacent to the breakwater about 800 yards from the Outer Harbor entrance.

(d) YFN - 693 was washed out of the AFDM-8 during the typhoon and rested on the bottom immediately to the east of the dock.

(e) The privately-owned hulk ADAK ISLAND, an ex-LST, parted its mooring wire and was driven aground against the inner end of the Glass Breakwater.

CONCLUSIONS:

It is readily apparent that in a severe typhoon situation such as Karen, none of the berths/buoys in Apra Harbor are safe. However, for less intense wind situations (say approximately 50 kt maximum) the inner Apra Harbor appears to provide some protection. Although there is limited information on which to base this judgement, it appears the preferred berths would be in the inner harbor, and in the upwind section of the harbor.

APPENDIX C

PORT FACILITIES FOR APRA HARBOR, GUAM

1. PIERS

Berth	Length	Depth at MLW
A	600'	44'
B	600'	35'
D	663'	42'
E	744'	40'
H	530'	32'
L1	570'	26'
L2	570'	34'
M	275'	34'
N	550'	34'
O	560'	34'
P	520'	34'
Q	257'	30'
R1	516'	32'
R2	516'	33'
S1	500'	35'
S2	500'	35'
S3	393'	33'
S4	494'	30'
T1	498'	29'
T2	498'	32'
T3	450'	32'
U1	450'	32'
U2	450'	32'
V1	482'	30'
V2	482'	29'
V3	200'	30'
V4	280'	31'
V5	660'	30'
V6	660'	30'
X1	493'	32'
X2	493'	31'
X3	493'	29'

Wharves F and G are not included in the above list since they are controlled by the Government of Guam, Commercial Port.

2. MOORING BUOYS

NUMBER	SIZE & TYPE		LOCATION	DEPTH	HOLDING POWER
951	17'X10'6"	AA	O/H SOUTH	125'	300,000 LBS
701	9'6"X12'	A	O/H SOUTH	167'	150,000 LBS
702	9'6"X12'	A	O/H NORTH	150'	150,000 LBS
703	9'6"X12'	A	O/H NORTH	140'	150,000 LBS
704	9'6"X12'	A	O/H SOUTH	120'	150,000 LBS
501	10'6"X6'6"	B	O/H NORTH	160'	125,000 LBS
502	10'6"X6'6"	B	O/H NORTH	157'	125,000 LBS
302	10'6"X6'6"	C	O/H NORTH	115'	100,000 LBS
303	10'6"X6'6"	C	O/H NORTH	108'	100,000 LBS
201	9'6"X5'6"	D	O/H SOUTH	105'	75,000 LBS
202	9'6"X5'6"	D	O/H SOUTH	108'	75,000 LBS
12/13	9'6"X5'6"	D	O/H SOUTH	105'	75,000 LBS
12-	9'6"X5'6"	D	O/H SOUTH	105'	75,000 LBS
13	9'6"X5'6"	D	O/H SOUTH	97'	75,000 LBS
14	9'6"X5'6"	D	O/H SOUTH	97'	75,000 LBS
14/15	9'6"X5'6"	D	O/H SOUTH	97'	75,000 LBS
15/16	10'6"X6'6"	D	O/H SOUTH	97'	75,000 LBS
16	10'6"X6'6"	D	O/H SOUTH	87'	75,000 LBS
17	9'6"X5'	D	O/H SOUTH	69'	75,000 LBS
25-N	9'6"X5'	B	I/H	46'	125,000 LBS
25-S	9'6"X5'	B	I/H	48'	125,000 LBS
26-E	9'6"X5'	B	I/H EAST	48'	125,000 LBS
26-W	9'6"X5'	B	I/H WEST	48'	125,000 LBS
27-E	9'6"X5'	B	I/H EAST	37'	125,000 LBS
27-W	9'6"X5'	B	I/H WEST	32'	125,000 LBS
28-E	9'6"X5'	B	I/H EAST	36'	125,000 LBS
28-W	9'6"X5'	B	I/H WEST	36'	125,000 LBS
23	9'X12'	B	O/H EAST	58'	125,000 LBS
23/22	9'X12'	B	O/H EAST	58'	125,000 LBS
22	9'X12'	B	O/H EAST	58'	125,000 LBS

3. SERVICE CRAFT

CLASS	CAP	HULL	LENGTH	DRIFT	SPEED	RANGE	CARGO	REMARKS
YTB-777	360 TONS	STEEL	103'	16'3"	10KT	2,000 MI		
YTB-796	360 TONS	STEEL	103'	16'3"	10KT	2,000 MI		
YTB-795	360 TONS	STEEL	103'	16'3"	10KT	2,000 MI		
YTM-408	310 TONS	STEEL	101	12'	8	5,700		
YTM-409	310 TONS	STEEL	101	12'	8	5,700		
YON-267	1,445 TONS	STEEL	165'	8'			8,500 BBLS	PUMP CAP 58,000 GPH
YOGN-120	1,360 TONS	STEEL	120'	8'			5,076 BBLS	PUMP CAP 58,000 GPH
YFN-814	590 TONS	STEEL	110'	8'			430 TONS	
YC-1458	630 TONS	STEEL	110'	7'			500 TONS	
YC-1468	630 TONS	STEEL	110'	7'			500 TONS	
LCM-31	30 TONS	STEEL	50'	4'6"	9.5			OPEN CARGO WELL (WORK BOAT)
LCM-39	30 TONS	STEEL	50'	4'6"	9.5			OIL SKIMMER
LCM-33	30 TONS	STEEL	50'	4'6"	9.5			OPEN CARGO WELL
LCM-103	30 TONS	STEEL	50'	4'6"	9.5			CLOSED CARGO WELL (PUSHER #1)
LCM-708	30 TONS	STEEL	50'	4'6"	9.5			CLOSED CARGO WELL (PUSHER #2)
LCM-756	30 TONS	STEEL	50'	4'6"	9.5			CLOSED CARGO WELL (PUSHER #3)
ADM BARGE	30,000 LBS	WOOD	45'	3'	20KT	200 MI	6,525 LBS	
TARGET SLED	4,800 LBS	STEEL	25'	1'6"				24' WIDE WILLIAMS (TYPE)
CAMELS		STEEL	39'X19'4"	3'9"				TWO AMMY PONTOONS

APPENDIX D

SHIP SPEED VS SEA STATE AND WIND CHARTS

Figures D-1(a) and D-1(b) represent the estimated resultant speed of advance of a ship in a given sea condition. The original relationships were based on data of speed versus sea state obtained from studies of many ships by James, 1957. They should not be regarded at truly representative of any particular ship (Nagle, 1972).

For example, from Figure D-1(a), for a ship making 15 kt encountering waves of 16 ft approaching from 030° (relative to the ship's heading) one can expect the speed of advance to be slowed to about 9 kt. Twenty feet seas, under the same conditions, would result in a speed of advance of slightly less than 6 kt. However, it is emphasized that these figures are averages and the true values will vary slightly from ship to ship.

Figure D-2 shows the engine speed required to offset selected wind velocities for various ship types (computed for normal loading conditions).

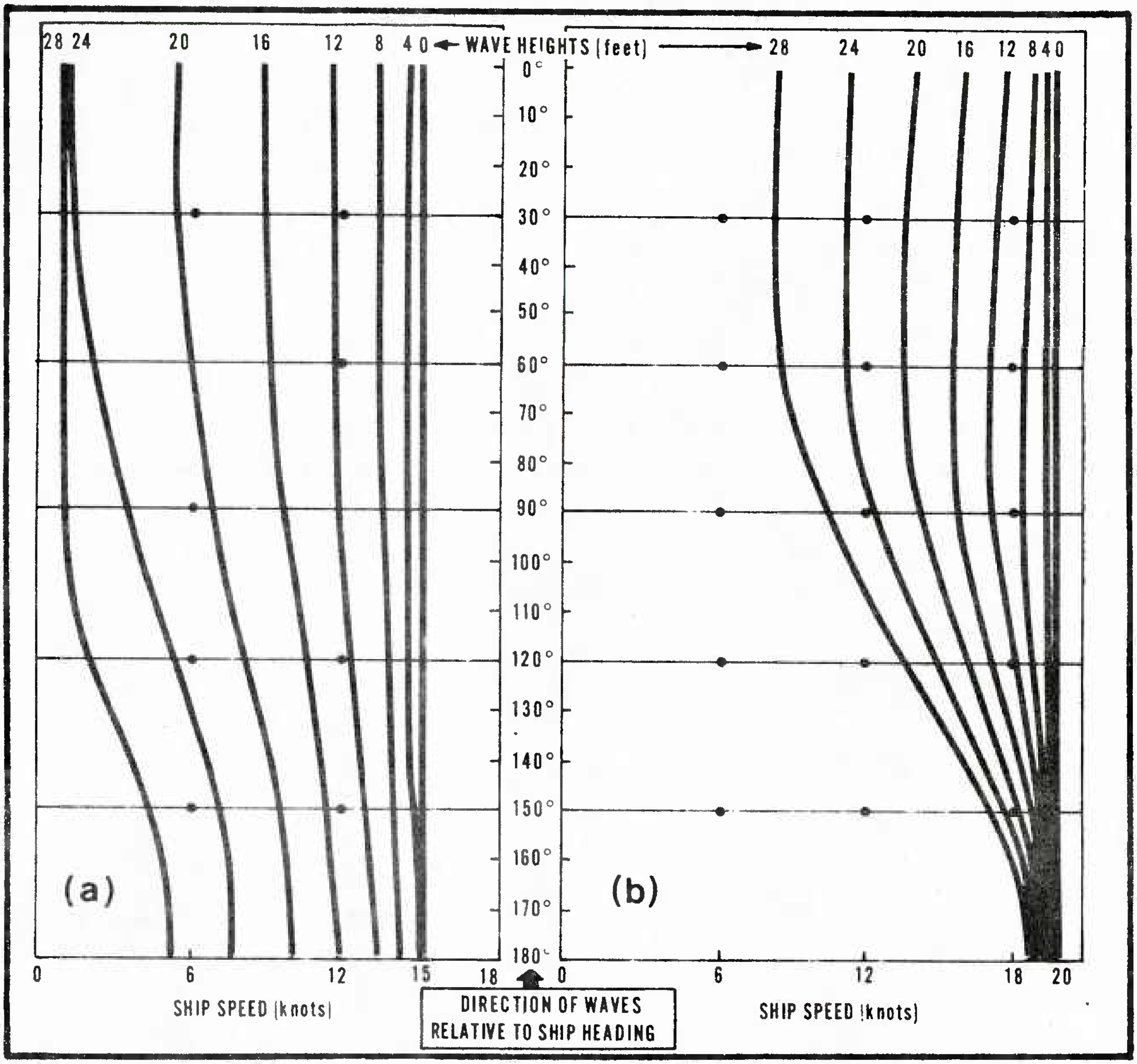
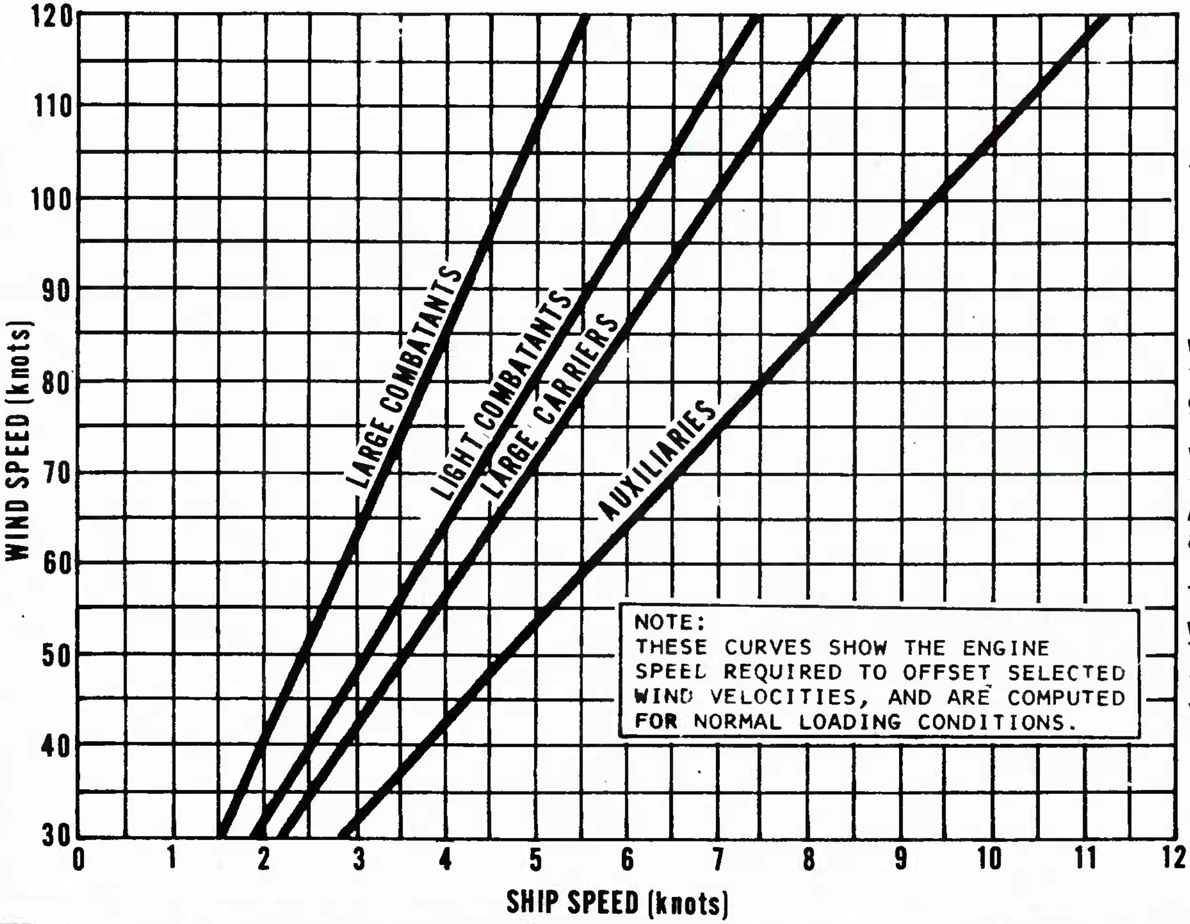


Figure D-1. Expected ship speed as a function of wave height and wave direction relative to ship's heading for a ship making 15 kt (a) and 20 kt (b) (from Nagle, 1972).



The curves shown were developed using the basic formula:

$$\text{WIND LOAD} = R_w A V^2$$

where R_w is equal to wind friction factor. (R_w is generally taken as 0.004.)

V is equal to wind velocity in knots
A is equal to projected area above the waterline in sq ft.

Three sets of calculations with varying R_w were used. The plotted values illustrated represent the mean of these values.

Figure D-2. Engine speed as a function of wind velocity for offsetting force of wind (from Crenshaw, 1965).

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